Technical Report

Demonstration of Advanced Geophysics and Classification Methods on Munitions Response Sites Closed Castner Range Fort Bliss, TX

ESTCP Project MR-201230

April 2016

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FINAL REPORT

Demonstration of Advanced Geophysics and Classification Methods on Munitions Response Sites

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Fort Bliss, TX

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14. ABSTRACT
This document serves as the Environmental Security Technology Certification Program (ESTCP) Demonstration Report for the demonstration of advanced geophysics and classification technologies on the Closed Castner Range Munitions Response Site. This project is one in a series of projects funded by ESTCP to use advanced geophysical sensors and test data analysis tools for anomaly classification.

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ACRONYMS

CCR	Closed Castner Range
CD	Cultural Debris
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm	centimeter
DERP	Defense Environmental Restoration Program
DGM	Digital Geophysical Mapping
DoD	Department of Defense
EMI	Electromagnetic Induction
ESTCP	Environmental Security Technology Certification Program
ft	foot/feet
GPS	Global Positioning System
HE	High Explosive
ID	Identification
IDA	Institute for Defense Analysis
IMU	Inertial Measurement Unit
ISO	Industry Standard Object
IVS	Instrument Verification Strip
Lbs	pounds
LM	Library Matching
m	meter
mm	millimeter
MD	Munitions Debris
MDAS	Material Documented as Safe
MEC	Munitions and Explosives of Concern
MMRP	Military Munitions Response Program
MP	Man-Portable
MPPEH	Material Potentially Presenting an Explosive Hazard
MRS	Munitions Response Site
MYBP	Million Years Before Present
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
Nfa	Number of False Alarms
NRL	Naval Research Laboratory
Pclass	Probability of Correct Classification of TOI
QC	Quality Control
RMS	Root Mean Square
ROC	Receiver Operating Characteristic
RRD	Range-related Debris
RTK	Real-Time Kinematic
SARA	Superfund Amendments and Reauthorization Act
SI	Site Inspection
TEMTADS	Time-domain Electromagnetic Multi-sensor Towed Array Detection System
TOI	Target of Interest
TSC	Trimble Survey Controller

URS	URS Group, Inc.
U.S.	United States
USACE	U.S. Army Corps of Engineers
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance

1.0 INTRODUCTION

This document serves as the Environmental Security Technology Certification Program (ESTCP) Demonstration Report for the Demonstration of Advanced Geophysics and Classification Methods on the Closed Castner Range (CCR) Munitions Response Site (MRS) at Fort Bliss, El Paso, Texas. This project is one in a series of projects funded by ESTCP to test the effectiveness of advanced geophysical sensors and physics-based data analysis tools for anomaly classification.

The project purpose is to locate and interrogate anomalies with the Time-domain Electromagnetic Multi-sensor Towed Array Detection System (TEMTADS) and the advanced data analysis methods contained in the UX-Analyze extension to Geosoft's Oasis Montaj in a production environment to characterize a 5-acre study area at CCR.

1.1 BACKGROUND

ESTCP contracted URS Group, Inc. (URS) to use TEMTADS Man-Portable (MP) 2x2 in a litter configuration to perform a dynamic survey of the 5-acre study area and a cued survey of selected anomalies. Survey data were processed using Oasis Montaj. URS identified over 3,000 anomalies in the study area, approximately half of which were selected for cued data collection. URS processed and demonstrated the use and performance of advanced anomaly classification methods using the TEMTADS cued data. URS intrusively investigated 1,525 anomaly locations. Project points of contact are in Appendix A.

1.2 OBJECTIVE OF THE DEMONSTRATION

Digital geophysical mapping (DGM) of former military ranges results in the identification and location of subsurface anomalies at a site. Typically, very small fractions of these anomalies are munitions and explosives of concern (MEC). The majority of these anomalies are harmless metallic objects (e.g., munitions fragments, small arms projectiles, range-related debris [RRD], or cultural debris [CD]). ESTCP and other collaborators have developed advanced EMI sensors and geophysical data processing methods that have proven effective at classifying subsurface metallic objects as either targets of interest (TOI) (i.e., objects having the size, shape, and wall thickness associated with MEC) or non-targets of interest (non-TOI) (i.e., harmless scrap metal). This demonstration serves to:

- Demonstrate the cost and performance of these sensors and methods on increasingly challenging MRSs,
- Train Military Munitions Response Program (MMRP) contractors on the application of these sensors and methods to facilitate technology transfer and industry-wide adoption, and
- Identify opportunities for potential improvement of the sensors and classification methods.

1.3 REGULATORY DRIVER

The ESTCP Live Site Demonstrations are executed under the guidance of the Department of Defense (DoD) MMRP, which is a portion of the Defense Environmental Restoration Program (DERP). DERP is the DoD program to execute environmental response consistent with the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA); the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40

Code of Federal Regulations [CFR] 300); and Executive Order 12580, Superfund Implementation.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

2.1.1 Geophysical Data Collection

URS used the TEMTADS 2x2 configuration developed by United States (U.S.) Naval Research Laboratory (NRL) generally as described in the "User's Guide TEMTADS MP 2x2 Cart, v1.00," dated 5 June 2013. However, due to the vegetation and variable terrain at the CCR, instead of using a cart, the TEMTADS was configured for litter mode using parts supplied by NRL. For litter mode, the push handle was removed, the wheels were replaced with two ski-shaped runners, and a new mount above the array was used to hold the Inertial Measurement Unit (IMU) and Trimble R8 Real Time Kinematic (RTK) Global Positioning System (GPS) and to suspend the array between two ten-foot (ft) fiberglass poles (Figure 1).

Dynamic data collection required three personnel to operate: front and rear litter carriers as well as a tablet computer operator. The rear litter carrier also carried the backpack-mounted data acquisition computer, which was accessed and controlled wirelessly using a handheld tablet (Figure 2). The tablet operator used the TEMTADS tablet while walking behind the litter and marking transects with paint to maintain lane control. Due to the weight of the array (approximately 125 pounds [lbs]) and computer backpack (approximately 35 lbs), the litter operators fabricated and used harnesses to alleviate some of the hand-held load for dynamic data collection, and personnel rotated through the three positions throughout each day.

Cued data collection was performed by only the front and rear litter carrier personnel. The front litter carrier operated the TEMTADS tablet and the Trimble Survey Controller (TSC), which was used to navigate to pre-loaded anomaly locations provided by the project geophysicist. The field team switched from the original NRL-provided backpack to a lighter external frame backpack with alternate equipment configuration for use during cued data collection. The alternate configuration allowed for easier access to check battery indicator levels, and the field team was able to swap batteries without having to remove the backpack (Figure 3).

Figure 1. TEMTADS Litter Mode Configuration

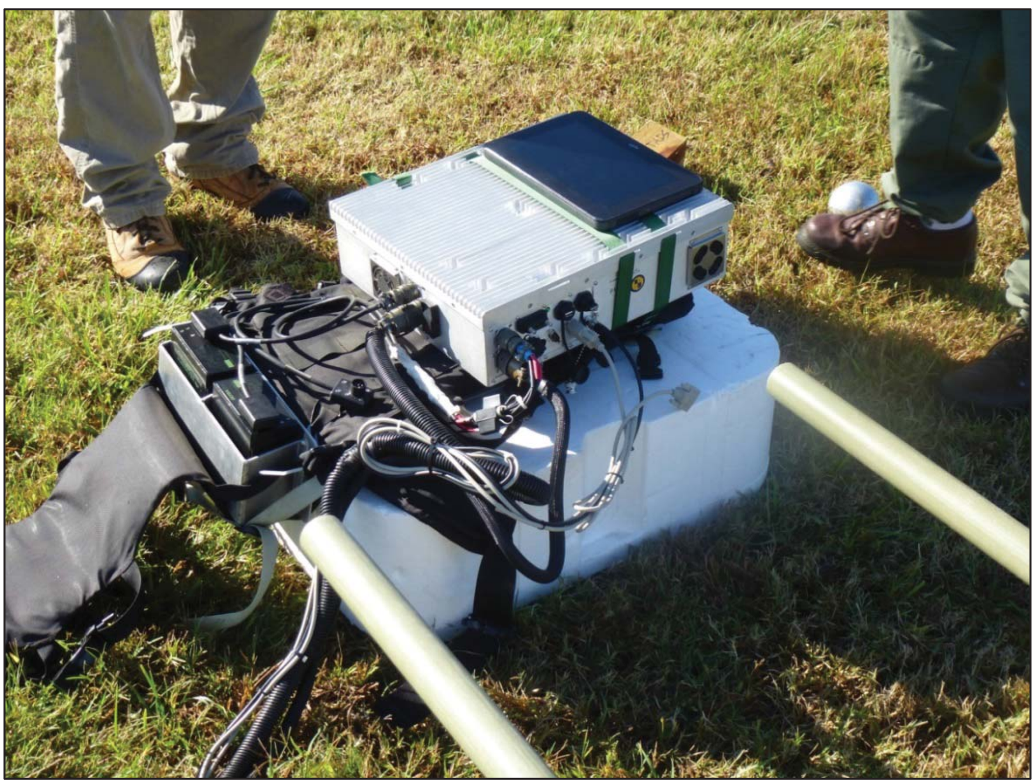

Figure 2. TEMTADS Computer Mounted on Original Backpack (Open for Inspection)

Figure 3. Battery Locations on Original and External Frame Backpack Configurations

2.1.2 Classification Methods

URS collected and processed dynamic and cued TEMTADS data using commercially available processing software. URS used the Library Matching (LM) tool within the UX-Analyze extension to Geosoft's Oasis Montaj to classify anomalies as TOI and non-TOI from the TEMTADS cued data. Anomalies were classified into four categories:

- Category 0: Cannot analyze
- Category 1: Likely TOI
- Category 2: Cannot decide
- Category 3: Likely non-TOI

Details of the classification process are described in Section 6.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.2.1 Dynamic Data Collection with TEMTADS 2x2 Litter

Variations in the TEMTADS sensor height above ground surface can cause a higher or lower than expected instrument response. For the dynamic data collection litter-mode configuration of TEMTADS, the intended sensor height was approximately 35 centimeters (cm), which was selected based on the equipment design and ergonomics (e.g., lowest comfortable hand-held

height). While the instrument height was measured on flat ground frequently throughout the day, maintaining consistent sensor height during dynamic data collection in litter mode was difficult. The length of the poles and size of the array precluded the ability maintain consistent instrument height across uneven terrain, which was especially pronounced while traversing the narrow arroyos. Flex in the fiberglass pole material and oscillation from natural walking motion led to amplified bouncing and swaying of the array, which increased as speed increased. This motion caused variations in instrument height as well as some slippage of the harnesses, which required stopping periodically to measure instrument height and adjust straps. For the cued data collection in litter mode, the instrument height was 15 cm above the ground surface based on the height of risers between the runners and array. By comparison, the cart-mounted configuration of TEMTADS has a relatively smaller footprint and maintains a more consistent and lower array height for both dynamic and cued data collection (based on the fixed wheel height, typically 20 cm).

2.2.2 TEMTADS Dynamic Data Processing

Compared to a typical EM61 survey, the TEMTADS dynamic survey generated more files that were larger in size, and data processing was time consuming. The large file sets made it difficult to share data and collaborate with non-local colleagues. The increased processing time made it more time consuming to experiment and discover better ways of handling the data (e.g., determining the best background subtraction files), so processing relied heavily upon the scripts and workflows developed by SAIC/Leidos.

3.0 PERFORMANCE OBJECTIVES

Performance objectives for the demonstration, provided in Table 1, serve as a basis for the evaluation of the performance and costs of the demonstrated technology. These objectives are for TEMTADS dynamic data and cued data collection, and data analysis and classification.

Table 1. Quantitative Performance Objectives for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria
Data Collection Objectives			
Along-line measurement spacing	Point-to-point spacing from dataset	Mapped survey data	90% <25 cm along-line spacing
Complete coverage of the demonstration site	Footprint coverage	Mapped survey data	≥85% coverage at 0.6 meter (m) line spacing and ≥98% coverage at 0.75 m line spacing calculated using UX-Process Footprint Coverage Quality Control (QC) Tool
Repeatability of IVS measurements	Amplitude of IVS seed items Measured target locations	Twice-daily IVS survey data	*Advanced Sensors Dynamic Survey:* Root Mean Square (RMS) amplitudes ±30% at the 14^{th} time gate. Down-track inverted location ±30 cm
			Advanced Sensors Cued: Polarizabilities ±10%
Cued interrogation of anomalies	Instrument position	Cued mode data	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location
Detection of all TOI	Percentage of detected seed items	Location of seed items and anomaly list	100% of seed items detected with 60 cm halo
Analysis and Classification Objectives			
Maximize correct classification of TOI	Percentage of TOI placed in Category 1	Prioritized anomaly lists and dig results	Correctly classify 100% of TOI
Maximize correct classification of non-TOI	Percentage of correctly classified non-TOI	Prioritized anomaly lists and dig results	>75% of non-TOI classified in Category 3 while retaining all TOI
Specification of no-dig threshold	Percentage of TOI placed in Categories 1 or 2 and percentage of non-TOI placed in Category 3	Prioritized anomaly lists and dig results	Threshold specified to achieve criteria above
Minimize number of anomalies that cannot be analyzed	Percentage of anomalies classified as Category 0	Inverted TEMTADS cued mode data and prioritized anomaly dig list	Reliable target parameters can be estimated for >95% of anomalies on the sensor's detection list
Correct estimation of target parameters	Accuracy of estimated target parameters for seed items	Estimated and actual parameters (polarizabilities, XY locations, and depths [Z]) for seed items	Polarizabilities ±20% X, Y <15 cm (or 1 σ) Z <10 cm (or 1 σ)

3.1 OBJECTIVE: ALONG-LINE MEASUREMENT SPACING

The ability of the dynamic TEMTADS survey to detect subsurface metallic objects depends on complete coverage of the site. Along-line measurement spacing must be close enough to ensure detection.

3.1.1 Metric

The metrics for this objective are the percentage of data points within acceptable along-line spacing.

3.1.2 Data Requirements

Each mapped data file will be compared to this objective.

3.1.3 Success Criteria

This objective is considered met for the TEMTADS if at least 90% of the mapped data points are less than 25 cm from the neighboring data point along the survey line.

3.2 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

The ability of the dynamic TEMTADS survey to detect subsurface metallic objects depends on complete coverage of the site. Data spacing must be close enough to ensure detection.

3.2.1 Metric

The metric for this objective is the footprint coverage as measured by the UX-Process Footprint Coverage QC Tool.

3.2.2 Data Requirements

Each mapped data file will be used to judge the success of this objective.

3.2.3 Success Criteria

This objective is considered met if the survey achieved at least 85% coverage at 0.6 meter (m) line spacing and 98% at 0.75 m line spacing calculated using the UX-Process Footprint Coverage QC Tool.

3.3 OBJECTIVE: IVS RESULTS

This objective demonstrates that the sensor system was in good working order and collecting valid data each day. The IVS will be surveyed twice daily. The amplitudes of the derived response coefficients for each emplaced item will be compared to the running average of the demonstration for reproducibility. At the beginning of the project, the IVS will be run five times to establish the baseline values. The extracted fit locations of each item will be compared to the reported ground truth and the running average of the demonstration.

3.3.1 Metric

The reproducibility of the measured responses of the sensor system to the emplaced items and of the extracted locations of the emplaced items defines this metric.

3.3.2 Data Requirements

Twice daily IVS survey data will be used to judge this objective.

3.3.3 Success Criteria

The objective will be considered met if the Root Mean Square (RMS) amplitude variation of the derived response coefficients is less than 30% and the down-track fit location of the anomaly is within 30 cm of the corresponding seeded item's stated location. The cued mode IVS objective is considered met if the standard deviation of the estimated polarizabilities is within 10% of the mean.

3.4 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

The reliability of cued mode data depends on acceptable instrument positioning during data collection in relation to the actual anomaly location.

3.4.1 Metric

The reliability of cued mode data depends on acceptable instrument positioning during data collection in relation to the actual anomaly location.

3.4.2 Data Requirements

The data will be used to judge this objective.

3.4.3 Success Criteria

The objective is considered met if 100% of anomalies are detected within 40 cm of the target location.

3.5 OBJECTIVE: DETECTION OF ALL TARGETS OF INTEREST

The collection of quality data should lead to a high probability of detecting TOI at the site.

3.5.1 Metric

The metric for this objective is the percentage of seed items that are detected using the specified anomaly selection threshold.

3.5.2 Data Requirements

The data will be used to judge this objective.

3.5.3 Success Criteria

The objective is considered met if 100% of the seeded items are detected within a halo of 60 cm.

3.6 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF TARGETS OF INTEREST

This is one of the two primary measures of the effectiveness of the classification method. By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms, URS expected to be able to classify the targets with high efficiency.

This objective concerns the component of the classification problem that involves correct classification of TOI.

3.6.1 Metric

The metric for this objective is the number of items on the anomaly list for a particular sensor that can be correctly classified as TOI.

3.6.2 Data Requirements

URS prepared a ranked anomaly list for the targets on the sensor anomaly list. Institute for Defense Analysis (IDA) personnel used scoring algorithms to assess the results.

3.6.3 Success Criteria

The objective is considered to be met if all of the TOI are correctly labeled as TOI on the ranked anomaly list.

3.7 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TARGETS OF INTEREST

This is the second of the two primary measures of the effectiveness of the classification method. By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms, URS expected to be able to classify the targets with high efficiency. This objective concerns the component of the classification problem that involves false alarm reduction.

3.7.1 Metric

The metric for this objective is the percentage of non-TOI items that are correctly classified as non-TOI by the classification method.

3.7.2 Data Requirements

URS prepared a ranked anomaly list for the targets on the sensor anomaly list. IDA personnel used scoring algorithms to assess the results.

3.7.3 Success Criteria

The objective is considered to be met if more than 75% of the non-TOI items can be correctly labeled as non-TOI while retaining all TOI on the dig list.

3.8 OBJECTIVE: SPECIFICATION OF NO-DIG THRESHOLD

In a retrospective analysis, as performed in this demonstration, it is possible to determine the true capabilities of a classification process based solely on the ranked anomaly list submitted by each demonstrator. In a real-world scenario, all targets may not be dug, so the success of the approach depends on the ability of an analyst to accurately specify their dig/no-dig threshold.

3.8.1 Metric

The probability of correct classification of TOI (Pclass) and number of false alarms (Nfa) at the demonstrator-specified threshold are the metrics for this objective.

3.8.2 Data Requirements

URS prepared a ranked anomaly list with a dig/no-dig threshold indicated. IDA personnel used scoring algorithms to assess the results.

3.8.3 Success Criteria

The objective is considered to be met if URS sets a dig/no-dig threshold that results in more than 75% of the non-TOI items being correctly labeled as non-TOI, while correctly identifying all the TOI.

3.9 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Anomalies for which reliable parameters cannot be estimated cannot be classified by the classifier. These anomalies must be considered TOI and reduce the effectiveness of the classification process.

3.9.1 Metric

The number of anomalies for which reliable parameters cannot be estimated is the metric for this objective.

3.9.2 Data Requirements

URS provided a list of all parameters as part of the results submission, along with a list of those anomalies for which parameters could not be reliably estimated.

3.9.3 Success Criteria

The objective is considered to be met if reliable parameters can be estimated for more than 95% of the anomalies on the sensor's anomaly list.

3.10 OBJECTIVE: CORRECT ESTIMATION OF TARGET PARAMETERS

This objective involves the accuracy of the target parameters that are estimated in the first phase of the analysis. Successful classification is only possible if the input features are internally consistent. The obvious way to satisfy this condition is to estimate the various target parameters accurately.

3.10.1 Metric

Accuracy of estimation of target parameters is the metric for this objective.

3.10.2 Data Requirements

Each analyst in demonstration reports compared estimated parameters for the seed items to those expected.

3.10.3 Success Criteria

The objective is considered to be met if the estimated polarizabilities are within ± 20%, the estimated X, Y locations are within 15 cm (1 σ), and the estimated depths (Z) are within 10 cm (1 σ).

4.0 SITE DESCRIPTION

Fort Bliss is located in three counties, Dona Ana and Otero counties in New Mexico and El Paso County in Texas. The cantonment area is situated adjacent to the city of El Paso, Texas, just north of the city of Juarez, Chihuahua, Mexico. The installation encompasses approximately 1.1 million acres. Figure 4 is a location map of Fort Bliss.

The Closed Castner Range MRS on Fort Bliss is located within El Paso, Texas, between U.S. Highway 54 and the Franklin Mountains State Park and is approximately 15 miles south of the border with New Mexico. The MRS is now 7,007 acres, after acreage east of U.S. Highway 54 was transferred to non-DoD entities. The site contains medium and large caliber projectiles (including high explosives [HE], fragmentation, target practice), mortars, pyrotechnics, illumination flares, grenades, and small arms. Figure 5 is a map of the Closed Castner Range MRS with the ESTCP study area.

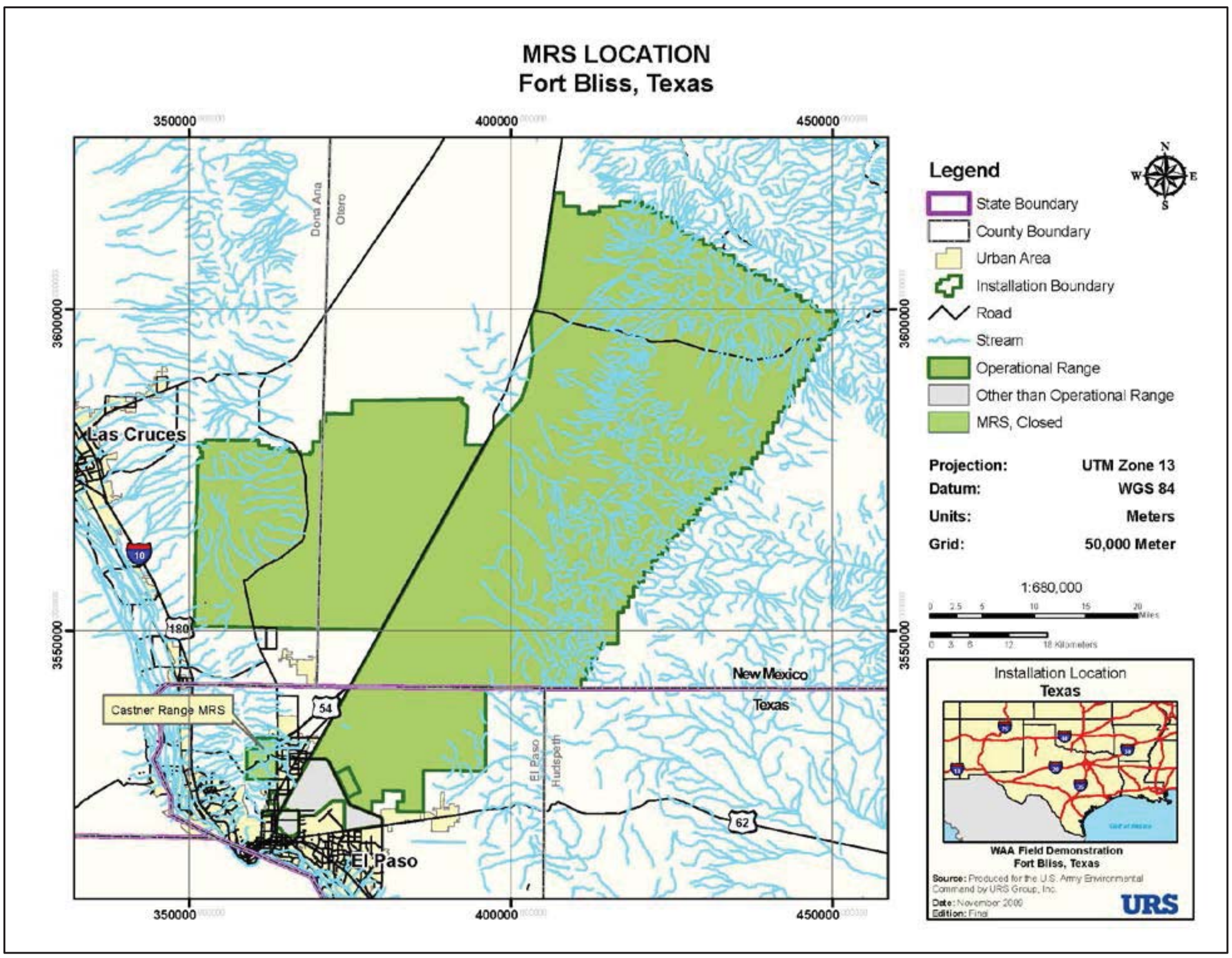

Figure 4. Map of Fort Bliss

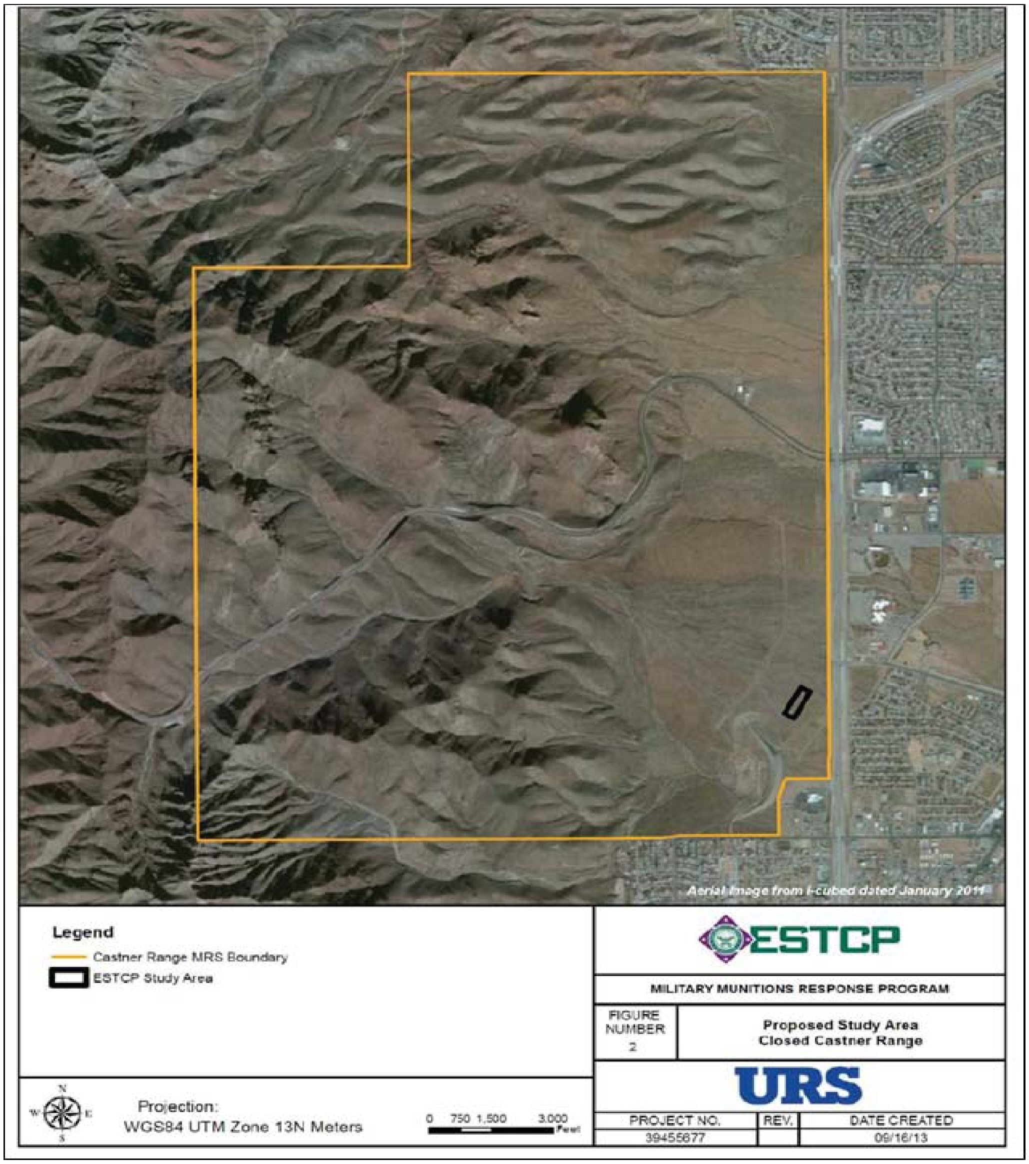

Figure 5. Closed Castner Range MRS and ESTCP Study Area

4.1 SITE SELECTION

This site was chosen as one in a series of sites for demonstration of the munitions classification process. Sites including this one provide opportunities to demonstrate the capabilities and limitations of the classification process on a variety of site conditions.

This site was selected for demonstration because of vegetation density, proximity of the study area to an alluvial fan containing ferrous rocks, as well as terrain. These features increase the site’s complexity, and the characteristics are likely to be encountered on production sites.

4.2 SITE HISTORY

During the war with Mexico in 1846, Colonel Alexander W. Doniphan and the 1st Missouri Mounted Volunteers became the first U.S. Army troops to enter the El Paso area. On November 7, 1848, the War Department directed the establishment of a post in El Paso to protect railways, stage routes, and settlers. The post was named Fort Bliss in honor of Lieutenant Colonel William Wallace Smith Bliss on March 8, 1854. El Paso established a permanent site for the post in 1890 and troops began to occupy the current location in 1893. The greatest period of growth for Fort Bliss occurred in response to a raid across the border by Pancho Villa, instigating a border control mission. World War II saw the cavalry dominance replaced by anti-aircraft artillery and the establishment of the installation as the largest overland air defense missile range and training center in the world. The U.S. Air Force closed neighboring Biggs Air Force Base in 1966 and turned it over to Fort Bliss (Fort Bliss 2001).

The acquisition of Castner Range began in 1926, initially encompassing approximately 3,500 acres. Additional land was acquired by 1939, bringing the range to 8,328 acres. Castner Range was heavily used for small arms firing courses and artillery firing and impact areas from 1926 until 1966 when ordnance use at Castner Range was discontinued. In 1972, the Department of the Army declared Castner Range surplus to its needs and began to transfer parcels to non-DoD entities. Many isolated clearance operations have been conducted on Castner Range. Approximately 1,244–1,321 acres (discrepancies exist in the record [e2M 2007]) east of U.S. Highway 54 have been cleared of UXO and have been transferred; however, the remaining 7,007 acres of the Closed Castner Range MRS have not been transferred and remain in the Army's control.

4.3 SITE GEOLOGY

The study area and vicinity were part of a relatively shallow marine shelf from the late Cambrian (600–500 million years before present [MYBP] through the early Pennsylvanian [310–280 MYBP] eras). Dolomite beds are from the late Cambrian to the late Ordovician (500–425 MYBP) and are the oldest sedimentary deposits in the area. Deposition during Devonian time consisted mainly of marine shales and shaly limestones. A relatively thin sequence of upper Mississippian age limestone and shale overlies the Devonian rocks. Uncomfortably overlying the Mississippian deposits are approximately 3,000 ft of Pennsylvanian age sediments. These strata consist of limestone, sandstone, dolomite, and shale, which were deposited in a shallow marine environment. Tectonic disturbances in Virgilian time (late Pennsylvanian) altered the sedimentation origin from marine to terrestrial. The tectonic movement resulted in the subject area becoming a large depression with landmasses developed to the east, west, and southwest.

In later Pennsylvanian and early Permian time, the Tularosa Basin received a thick sequence of land-derived sediments. Most sedimentary rocks in the area consist of limestone strata of the San Andres formation. These sediments mark the return of marine shelf deposition in the area. Broad regional uplift that occurred between 80 and 40 MYBP (Cenozoic Era) and differential drift within the North American Plate, which occurred 30 MYBP (Miocene), created fault patterns in the region. The result was a physiographic province characterized by down-dropped basins (grabens) bounded by tilted fault block mountains. These grabens have been filled with heterogeneous, unconsolidated to poorly consolidated sediments, which cover underlying sediments.

By middle Cenozoic time (present to 65 MYBP), the Hueco and the Mesilla bolsons on the east and west of the Franklin Mountains, respectively, were the prominent basins of deposition. There is evidence that the Tularosa Basin has had a history of continuous, closed basin deposition, with Kansas playa complexes possibly united with Lake Cabeza de Vaca and/or Lake Lucero to the north. Eroded petrocalcic horizons, braided stream deposits alternating with poorly sorted mudflows, relic and Paleozoic horizons, topographic expressions of old sediment surfaces and terrace strand lines, and multiple superimposed petrocalcic (caliche) horizons demonstrate several periods of alternatively wetter and drier climatic trends during and since the Pleistocene (0.01–2 MYBP).

The southern portion of the Tularosa Basin contains more than 6,000 ft of valley fill, stream sand, and gravel; rock slides; alluvial fans from mountains on either side; and lake deposits rich in salt and gypsum derived from sedimentary rocks of the adjacent ranges. Any rainfall or melted snowfall that occurs in the valley either seeps into the porous valley deposits or evaporates from small pools, leaving deposits of gypsum, salt, or other minerals. Fault lines along the edge of the Tularosa Basin may still be active, although no movement has been recorded in recent time. The mountain ranges adjacent to Fort Bliss developed during separate geologic periods and comprise a variety of minerals and soils. These geologically different mountain ranges generally contain site-specific substrates, creating areas of unique communities. The Fort Bliss region lies in an area considered to be of moderate seismic activity. The Franklin Mountains block has been rising and the Hueco Bolson block has been sinking for tens of millions of years. Earthquake data estimate that the strongest earthquake in the area in a 100-year period lies between a magnitude of 4.8 and 6.0 on the Richter scale (e2M 2007).

Relatively small deposits of Castner Limestone containing diabase (or dolerite) dikes and sills are located in the central portion of the site, west of the Fusselman Dam area. This area of potentially magnetic geology is in relatively higher elevations and steeper terrain. Magnetometer-based geophysical mapping was not performed in that area; however, magnetometer-based geophysical mapping was previously conducted in the lower elevations and generally flatter eastern part of the site approaching the demonstration site, which is downslope from these potentially magnetic flows. These deposits, although localized, could be a source of the magnetic interference experienced in this downslope area. It is possible that, before the installation of the dam, the potentially magnetic geology to the north of the dam eroded and was deposited in the alluvial fan on the flat eastern part of the site at the base of the Franklin Mountains. This is depicted in Figure 6.

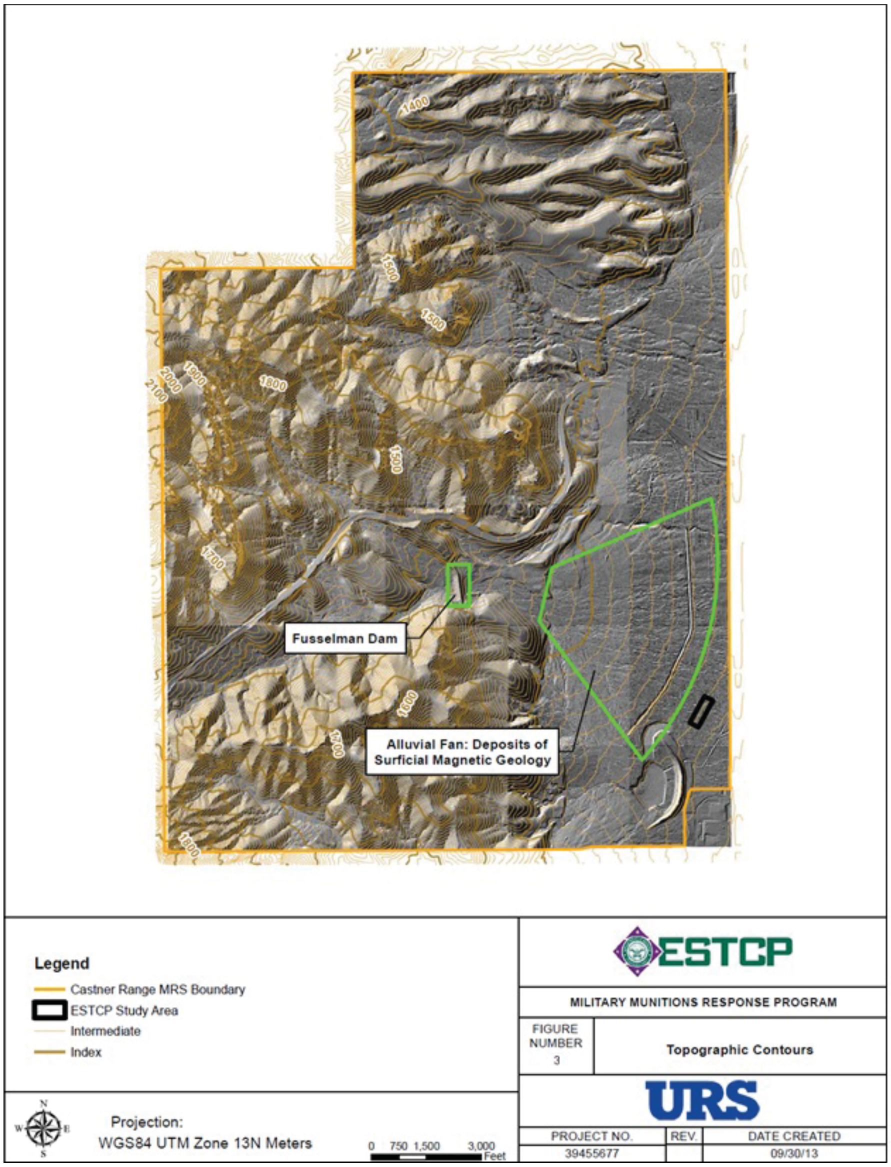

Figure 6. Areas Affected by Magnetic Deposits

4.4 MUNITIONS FIRED ONSITE

Based on records reviewed in the Site Inspection (SI) Report (e2M 2007), the Closed Castner Range MRS potentially contains munitions items related to flares; signaling items; training simulator devices; screening smoke; grenades (hand, rifle, smoke); small, medium, and large projectiles (20 millimeter [mm]–155mm); mortars; rockets; and small arms.

URS Group, Inc. conducted a Wide Area Assessment Field Demonstration project in CCR from 2009 to 2011, which included surface clearance actions and target anomaly investigations. MEC discovered during this project included 37mm projectiles and 2.36-in. rockets in addition to the discovery of a significant amount of 155mm HE projectile munitions debris (MD) (URS 2012).

5.0 TEST DESIGN

At the CCR demonstration site, URS performed:

- Overall site preparation and management (e.g., site preparation, validation digging),
- TEMTADS dynamic and cued survey data collection and processing, and
- Advanced instrument data analysis and anomaly classification.

During site preparation activities, URS trimmed limited vegetation and emplaced blind seeds at the demonstration site. URS collected both dynamic and cued mode data using the TEMTADS 2x2 in a litter configuration. URS geophysicists classified anomalies using the TEMTADS data. URS subsequently performed intrusive investigation of all anomalies selected for cued investigation to validate classification results.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

- **Demonstration/Work Plan Development**: URS prepared a demonstration plan describing site preparation, TEMTADS data collection, TEMTADS data processing, TEMTADS data analysis including classification, and intrusive investigation activities for this project.
- **Site Preparation:** URS used manual tools to cut most vegetation to 15 cm above ground surface to prepare the site for advanced sensor data collection. Sensitive vegetation such as cactus and some yucca were avoided to preserve the local ecosystem.
- **TEMTADS Data Collection:** URS dynamically surveyed 5.02 acres using TEMTADS 2x2 in a litter configuration with a nominal line spacing of 0.6 m and identified over 3,000 anomalies. URS also collected cued data over half of the dynamic survey area.
- **TEMTADS Data Processing**: URS used the Geosoft UX-Analyze software package to process the TEMTADS data.
- **TEMTADS Data Analysis and Classification**: URS used the inversion results for each of the cued targets to classify them using LM within the UX-Analyze package in Geosoft's Oasis Montaj software.
- **Intrusive Investigation**: URS intrusively investigated 1,525 anomalies. Each anomaly was photographed and attribute information (e.g., nomenclature, size, depth) was captured and provided to the ESTCP Program Office.

5.2 SITE PREPARATION

URS team members arrived on-site prior to arrival of the geophysical data collection team to set up project equipment and confirm the location of two previously emplaced geodetic control points. URS UXO technicians escorted the vegetation cutting team and emplaced blind seed items (60 small Industry Standard Objects [ISO]) at the site. The location, depth, and general orientation were recorded for each emplaced seed item.

5.3 CALIBRATION ACTIVITIES – INSTRUMENT VERIFICATION STRIP

URS used an IVS to verify the proper operation and functioning of the geophysical equipment and to measure site noise readings of the TEMTADS before and after each day of field data collection. The IVS also served to verify that geo-location systems provided accurate sensor location data. The daily tests in the IVS were consistent with the specifications and descriptions

contained in *Geophysical System Verification (GSV): A Physics-Based Alternative to Geophysical Prove Outs for Munitions Response* (ESTCP 2009).

The IVS initially was installed on 26 October 2013 with ISOs buried at various depths and orientations. The IVS items were repositioned at a uniform depth and orientation (Table 2) as per the work plan and the data were re-collected on 29 October 2013. ISOs were used as reference seed items. The IVS contained five seed items of the sizes, at the depths, and in the orientations listed in Table 2. A background IVS path was established parallel to and offset from the seeded IVS to collect dynamic background noise measurements.

Table 2. CCR Instrument Verification Strip

Item ID	Description	Easting (m)	Northing (m)	Depth (m)	Inclination	Orientation
ivs-01-new	Small ISO	363435.003	3527777.149	0.14	Horizontal	Along Track
ivs-02-new	Small ISO	363439.000	3527777.160	0.14	Horizontal	Along Track
ivs-03-new	Small ISO	363442.832	3527777.131	0.14	Horizontal	Along Track
ivs-04-new	Small ISO	363447.105	3527777.104	0.14	Horizontal	Along Track
ivs-05-new	Small ISO	363449.909	3527777.164	0.14	Horizontal	Along Track

* Coordinates UTM Zone 13N, WGS 1984.

5.4 DATA COLLECTION – TEMTADS ADVANCED SENSOR IN DYNAMIC SURVEY MODE

5.4.1 Sample Density

The dynamic mode survey consisted of complete coverage in the study area and subsequent data processing to identify metallic targets and create a prioritized target list. Figure 7 shows the dynamic data collection. Data were collected along parallel transects with 0.6 m nominal separation between transects, and at a sample rate and survey pace slow enough to ensure nominal down-line spacing of less than 25 cm. Additionally, the field team walked additional transects parallel to several arroyo features (generally perpendicular to the primary transect direction), which allowed for a more consistent instrument height and better quality data (see Sections 2.2.1 and 9.1.4). Survey position were recorded and logged during the dynamic survey using an RTK GPS. Survey lanes were marked using water soluble spray paint due to the inability to securely place flags in the dry, rocky soil. Areas within established grids that could not be mapped because of vegetation were noted in the geophysical logbook.

Figure 7 TEMTADS Dynamic Data Collection

5.4.2 Quality Checks

IVS: Survey personnel collected dynamic data over the IVS in each direction at the beginning and end of the data collection day. The field team also performed initial dynamic tests including offsets from the IVS centerline and varying walking speeds and instrument heights.

Background IVS: This test consisted of alternating passes directly over the background IVS at the beginning of each day. Responses were monitored for consistency and overall noise levels during later data analysis.

Battery Strength Test: At the beginning of the day and periodically throughout use, the survey personnel checked the battery power remaining and replaced batteries as necessary.

Instrument Height Verification: A height of 35 cm was ascertained as ideal to allow for quality data collection while considering terrain, ergonomic, and equipment design limitations.

Instrument Height was checked using a tape measure (Figure 8):

- At the beginning of each day before IVS collection;
- After the equipment was carried to the production area;
- Each time an operator changed places;
- After terrain caused extended oscillation of the equipment; and
- Whenever the operator felt the equipment was not at the correct height.

Figure 8. Instrument Height Verification

Verify Configuration: Prior to any data acquisition, the field team reviewed the configuration for the acquisition software.

5.4.3 Data Summary

Raw data were collected and stored as .tem files. The software provided the operator with the ability to input a prefix for the root name of the file (e.g., "102613"). The software then automatically appended a numeric character to the filename prefix to form a unique root name for the data file (e.g., 102613_001).

Discrete data files were created for each of the following events:

- Each time the IVS was performed;
- Each transect collected;
- Each time an issue with the system that could have a significant impact on data quality was identified and corrected (e.g., loose cable, twine caught on system, GPS error).

5.5 DATA COLLECTION – TEMTADS ADVANCED SENSOR IN CUED MODE

5.5.1 Sample Density

The dynamic data collection identified over 3,000 anomalies located in thirty grids. The, project team selected fifteen grids for full cued data collection, which allowed URS to collect data over 1,495 anomaly locations. Measurements were repeated as necessary due to offsets of the sensor relative to the anomaly source or other data quality issues. Additionally, background responses were measured periodically where no metallic source was known to be present. The field team

collected a total of approximately 2,200 cued data measurements including re-collect, background, and IVS measurements.

The survey team used the TSC and RTK GPS to navigate to each previously uploaded anomaly location and placed the array on the ground at that location. The front operator used the tablet to collect a cued data measurement (Figure 9). The instrument's pitch, roll, and yaw angles automatically were measured by the IMU. These angles and the GPS measurements were used to calculate the sensor center location.

The TEMTADS system allows for a real-time single-dipole inversion by the field team using the tablet. Using this function, the field team checked the instrument response and ensured the sensor was centered over each anomaly. If the sensor was located greater than 30 cm away from the center of a detected anomaly, the field team adjusted the sensor location accordingly and collected another cued data measurement. Recollects were also taken if the target was greater than 20 cm off the initial target and detected by fewer than two coils. The GPS coordinate and cued data for the new location was identified with the original anomaly identification (ID) plus a modifier indicating that it was an added data point offset from the original location.

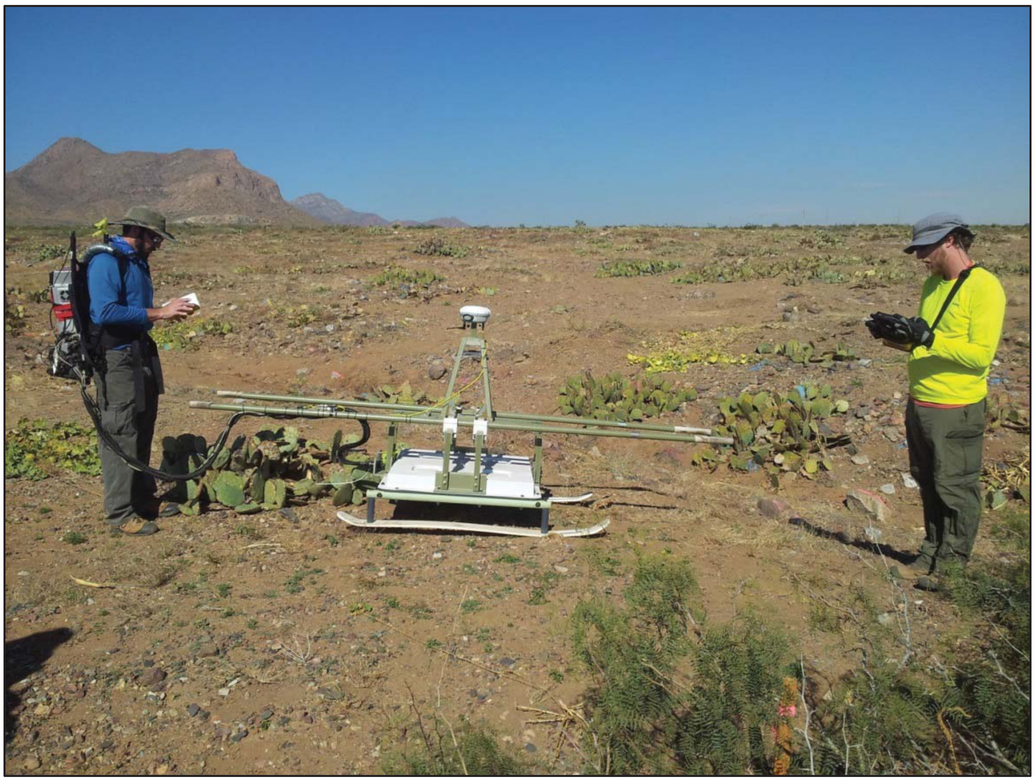

Figure 9. TEMTADS Cued Data Collection

5.5.2 Quality Checks

IVS: Cued responses were collected over each item in the IVS at the beginning and end of each day to demonstrate response repeatability over known sources.

Battery Strength Test: At the beginning of the day and periodically throughout use, data collection teams checked the battery power remaining and replaced batteries as necessary.

Background Response Measurement: Cued responses were collected at regular intervals at locations where dynamic data results indicated the presence of no metallic source. These locations represent the typical geologic response of the cued mode area. The nominal interval between background response measurements was one hour. Additional background measurements were taken when restarting equipment, replacing transmitter batteries, or field conditions changed (e.g., rain).

Verify Configuration and Initialization Files: Prior to any data acquisition, the field team reviewed the configuration and initialization files for the acquisition software. The field teams confirmed they had the appropriate configuration for the system setup.

5.5.3 Data Summary

Raw data were collected and stored as .tem files. The software provided the operator with the ability to input a prefix for the root name of the file (e.g., “112213”). The operator then appended an alpha (for IVS and daily tests) or numeric (for data collection) character to the filename prefix before a point was collected to form a unique root name for the data file (e.g., 112213a or 112213_1).

Discrete data files were created for each of the following events:

- Each IVS target;
- Each time a background point was collected;
- Each time a target anomaly location was collected;
- Each time a target anomaly location required an offset; and
- Each time an issue with the system that could have a significant impact on data quality was identified and corrected (e.g., program froze, GPS error, movement caused by loose soil or strong wind).

5.6 VALIDATION

5.6.1 Excavation Procedure

Intrusive investigations were completed in the Castner Range demonstration site to determine whether the identified targets were MEC, munitions debris, or harmless scrap.

A target list was derived from the TEMTADS dynamic data collection and associated data processing/analyses. The target list, in UTM coordinates with expected depth below ground surface, was provided to the reacquisition teams in tabular and grid map form on a Trimble Yuma tablet for recording electronic field notes and on a Trimble TSC3 for GPS navigation and recording. The reacquisition team navigated to the target location with Trimble TSC3 and R8 RTK GPS. Daily functional quality control (QC) tests were conducted for all reacquisition equipment, including White’s All Metal Detectors and RTK GPS.

Subsurface anomalies were manually excavated in accordance with EM 385-1-97 (USACE 2008). If no metallic objects greater than 2.5 cm were found after digging the reacquisition target location within a 30-cm radius circle to 10 cm below the specified depth, URS abandoned the dig location and reported the result as “no contact.”

5.6.2 Data Recording Procedure

The following data were recorded during intrusive investigation of anomalies.

- **Item Location**: The location of the item was recorded with an RTK GPS to a horizontal precision of 3 cm.
- **Depth**: The depth was measured in cm using a ruled straight edge from a horizontal guide at ground surface to the approximate center of the metal item.
- **Identification**: The item was described if it could be identified (e.g., 4.2-in. mortar base plate, aluminum can, large bolt, nail).
- **Digital Photograph**: A digital photograph of all metal items found at each anomaly location was taken with the items in front of a white background with visible ruled markings in cm and the anomaly number.
- **Number of Contacts**: URS recorded the number of discrete metal items (greater than 2.5 cm in size) found during the investigation of the anomaly location.

If more than one metal item was found when excavating a single target location, each item was recorded with an identical anomaly number.

5.6.3 Post Clearance

URS bagged all items recovered from each hole in a bag marked with the anomaly number. On completion of each anomaly, the hole was refilled to grade. Material potentially presenting an explosive hazard (MPPEH) was inspected and certified as material documented as safe (MDAS) by qualified UXO technicians. MDAS was shipped to a qualified scrap metal processor for final disposition.

5.6.4 Validation Results

Dig results including detailed descriptions, actual recovered locations, and photographs. All the seed items on the dig list were recovered. However, the locations for two seed items (seed 15 in grid C10 and seed 54 in grid C6) inadvertently were not selected in dynamic target picking (refer to Section 7) and subsequently omitted from the dig list (refer to Section 7.5). One MEC item was recovered during validation, a 105-mm projectile (CR-1284), and was properly disposed. Figure 10 shows a digital photograph of the recovered MEC item and relevant data.

Figure 10. MEC Recovered at CCR

6.0 DATA ANALYSIS AND PRODUCTS

6.1 TEMTADS DYNAMIC DATA PROCESSING AND INTERPRETATION

The TEMTADS dynamic data were imported and processed daily. URS used the UX-Analyze extension contained in Geosoft Oasis Montaj version 8. The processing procedures relied heavily upon the scripts and workflows developed by SAIC/Leidos. The first set of scripted commands filtered the transmitter currents, output reports on current channels, calculated time differences, flagged and interpolated over records with the same time, and calculated speed and heading. The second set of scripted commands created the "_located" database with median filtered monostatic responses, and created the channel of time gates 0 through 16 skipping time gate 1 (Figure 11). Time gate 1 was not used due to inherent instrument noise. The target selection criteria of 15 mV/Amp (current-corrected voltage) on the sum time gate channel was determined by taking the lowest expected detection response of a horizontal ISO at 0.14 m depth and applying a 20% buffer. The lowest expected ISO response of 19 mV/A was based upon twenty IVS runs collected over five days.

The standard deviation of background noise varied between 3 to 5 mV/A on the sum time gate channel, depending on the dataset. Using the higher background noise value of 5mV/A, a target selection criteria of three times the background standard deviation also yielded a target selection criteria of 15mV/A.

6.2 TEMTADS CUED DATA PROCESSING, ANALYSIS, AND CLASSIFICATION

Using the target selection threshold of 15 mV/A, approximately 3,000 anomalies were identified from the dynamic survey completed within the five-acre demonstration area. URS randomly selected 15 of the 30 grids within the demonstration area and collected cued data on all anomalies identified within the selected grids (Figure 12).

URS used the Geosoft UX-Analyze software package and scripts developed by SAIC/Leidos to process and invert the TEMTADS data. Upon import of the data, background files automatically were separated and placed into a database with the suffix "_background," and the remaining data files were placed into the output database. Background statistics and decay plots were generated, outlying background data were unselected from the database, and the data were leveled. An SAIC/Leidos script was used to run a single object solver, match betas to a library, create library match plots, merge flag XY locations, create TEM data maps, create dynamic data maps, create decay maps, calculate data metrics and flag out of specification targets using the "comments" channel.

Inversion results were reviewed to determine whether data would be of sufficient quality to classify the target anomaly source. Both single- and multi-source inversions were reviewed for data quality, to determine whether the inversion fits cohesions were greater than 0.8, signal amplitude was greater than 1 mV/Amp, and the inverted anomaly source locations were within 0.4 m of the TEMTADS location. Inverted results that did not meet these criteria were selected for re-collection. If the results were already re-collected data, no further attempts were made to collect additional data.

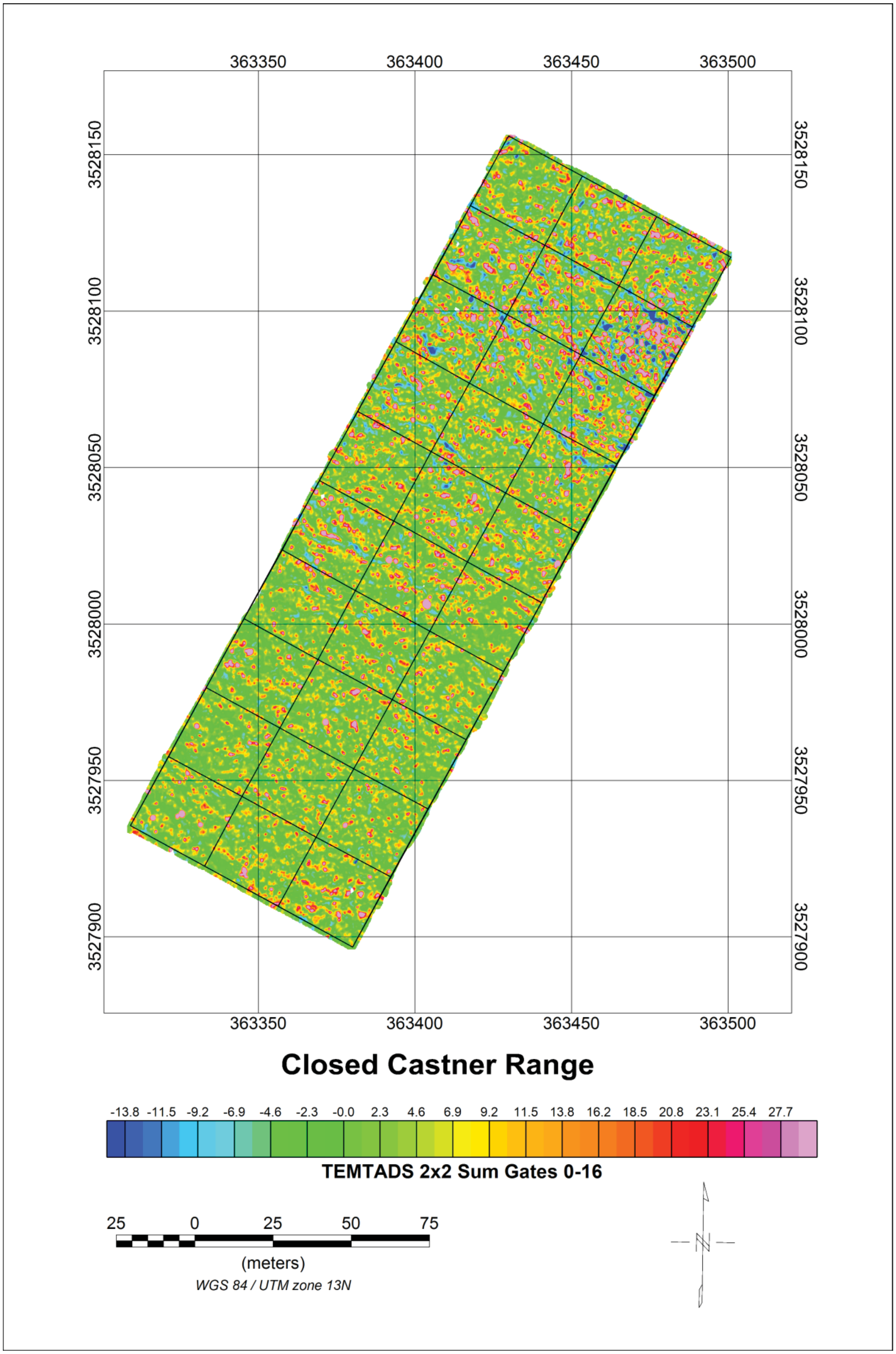

Figure 11. TEMTADS Dynamic Survey Results

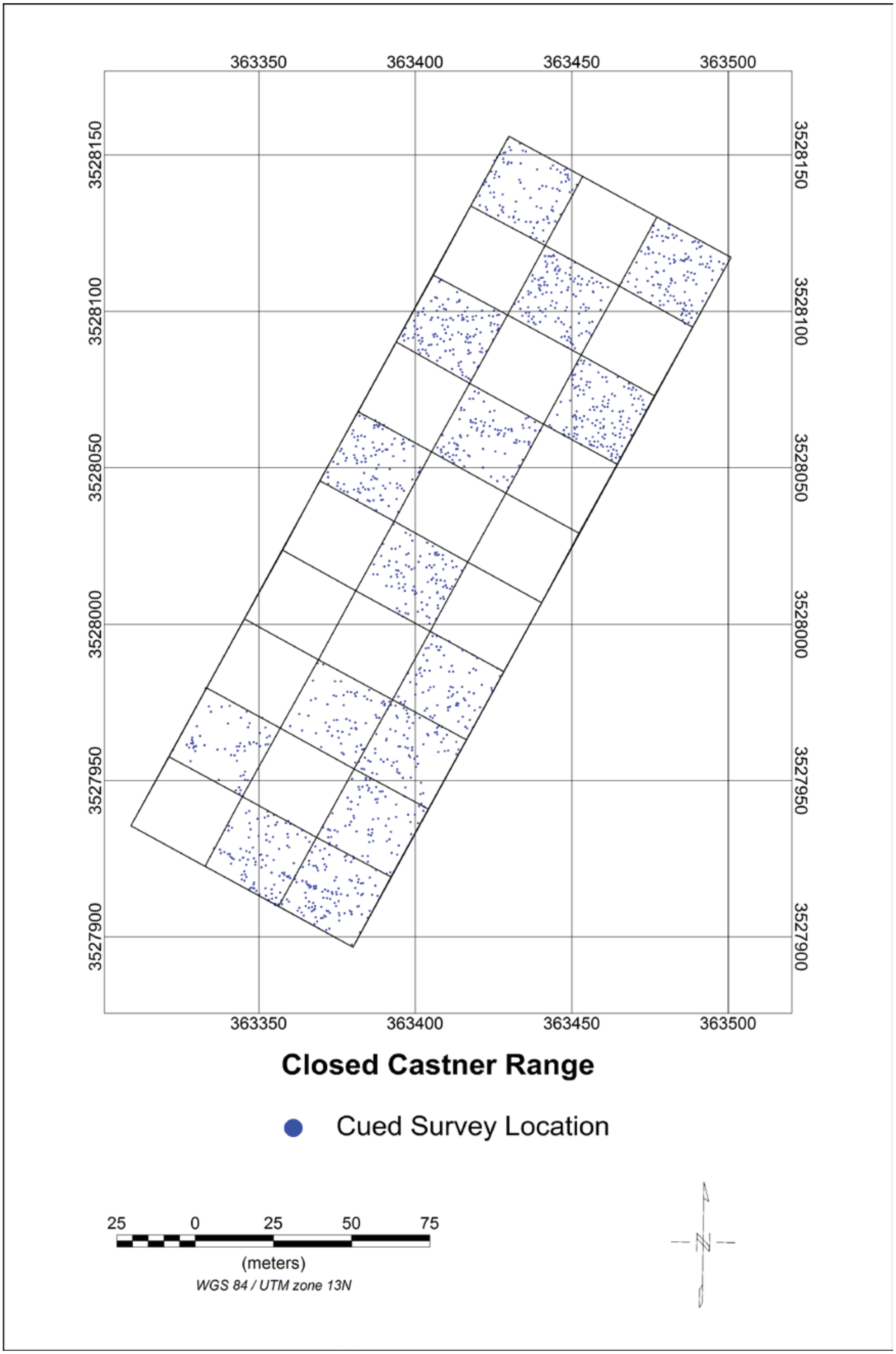

Figure 12. TEMTADS Cued Survey Locations

6.2.1 Prepare Data for Analysis

Software updates that occurred after field work completion have improved standardization of the workflow within UX-Analyze. Full cued data analysis and classification for CCR were performed using the UX-Analyze Process Data menu contained in Geosoft Oasis Montaj Version 8.3. Generally, default setting parameters were not overridden except where necessary to meet project-specific criteria. Prior to classification, cued data files were renamed to unique project area-wide identifiers independent of grid locations (CR-0001 through CR-1495). URS used files approved and provided by ESTCP to perform full classification. The following sections summarize the cued data classification process.

URS imported CCR cued data files for target and background locations into one Montaj project. Since UX-Analyze does not accept hyphens in file names, an underscore was used in place of a hyphen for each file name and associated Target ID (CR-0001 through CR-1495). Background files were denoted with "_b" at the end of the file name. URS mapped the target and background locations in Montaj to verify spatial distribution. Using UX-Analyze QC tools, URS reviewed survey data outlier flags (current, flatline, GPS, IMU, and saturation), statistics and decay plot overlays for each background location, and leveled the survey data (i.e., removed background) based on proximal time and location.

Using the UX-Analyze Field QC processing menu, URS modeled the targets and ran a single object solver library match against the full standard TEMTADS library. URS reviewed the size and decay map with library item overlay and polarization plot outputs. No revisions were made to the library at this stage of processing.

6.2.2 Validate Library

Using the Validate Library processing menu, URS compared single object, multiple object three criteria (111: Size β1, shape β2/β1, and shape β3/β1), and multiple object two criteria (110: Size β1, and shape β2/ β1) solutions to the full standard TEMTADS library. If a specific library item did not have a high match (>0.92) to any cued item at CCR, then the library item was removed from further consideration. A library overlay was created using the project-specific library and used in scatter analyses to select unexpected TOI for ground truth. Additionally, the Manage Library tool was used to flag clusters of items that did not have a good (<0.92) library match for ground truth. The first round of ground truth results confirmed seven TOI plus discovery of a new 37 mm TOI that URS added to the project-specific library.

6.2.3 Classify and Rank

Using the Classify and Rank processing menu, single and multiple (111 and 110 criteria) object solutions were matched to the validated library. A prioritized list was created using the highest matched item for each target location. Data quality thresholds factored into the category and subcategory rankings. Default thresholds were used for signal amplitude, fit depth, decay, size, fit coherence, and boundaries between TOI and non-TOI. Distance threshold defaults were used for the distance between array and flag and distance between flag and inverted location; however, based on the initial ground truth results, the distance threshold between the array position and inverted location was increased from 0.4 m to 0.42 m.

Additional ground truth locations were selected based on clusters and initial ground truth results. The second ground truth request resulted in confirmation of four TOI plus discovery of a second new 37 mm TOI that was added to the library. The Classify and Rank menu was re-run using the revised library, resulting in a new prioritized list.

ESTCP/IDA provided ground truth information for the dig portion of the prioritized list. A third new TOI (25 mm projectile) was found and added to the library. The Classify and Rank menu was re-run using the revised library. The initial portion of the prioritized list (already dug) was retained, but the undug portion of the list was reprioritized and additional items matching to the new 25mm projectile were added as digs.

6.2.4 Final Ranked Anomaly List

A ranked anomaly list based on the library match, clustering, and ground truth results was submitted to ESTCP/IDA.

6.3 DATA PRODUCTS

Table 4 provides the general prioritized target list statistics.

Table 3. General Prioritized Target List Statistics

List Name	TOI Identified		Training Targets		Cannot Analyze		List Length		Total Targets
	Qty.	%	Qty.	%	Qty.	%	Qty.	%	
FtBliss URS UXA-LM None 2x2 Custom s2v2	38	97%	131	9%	66	4%	639	43%	1,491

The URS prioritized target list using the UX-Analyze LM method identified 97% of the TOI in the dig portion of the list (Categories 1 and 2). This included a 105-mm projectile (MEC), 37-mm and 25-mm projectile frag (MD), and seeds. One TOI (CR-1341) was identified in Category 3, the no-dig portion of the list. Refer to Section 6.4.2 for additional information regarding CR-1341. The number of targets on the dig list (including training targets) was 639, which was 43% of the total cued targets. URS ranked fuzes as TOI in the final prioritized target list; however, fuzes were determined by ESTCP to be non-TOI for scoring purposes. Inclusion of fuzes resulted in 148 digs (Categories 1 and 2) that actually were non-TOI. The Receiver Operating Characteristic (ROC) Curve is presented as Figure 13.

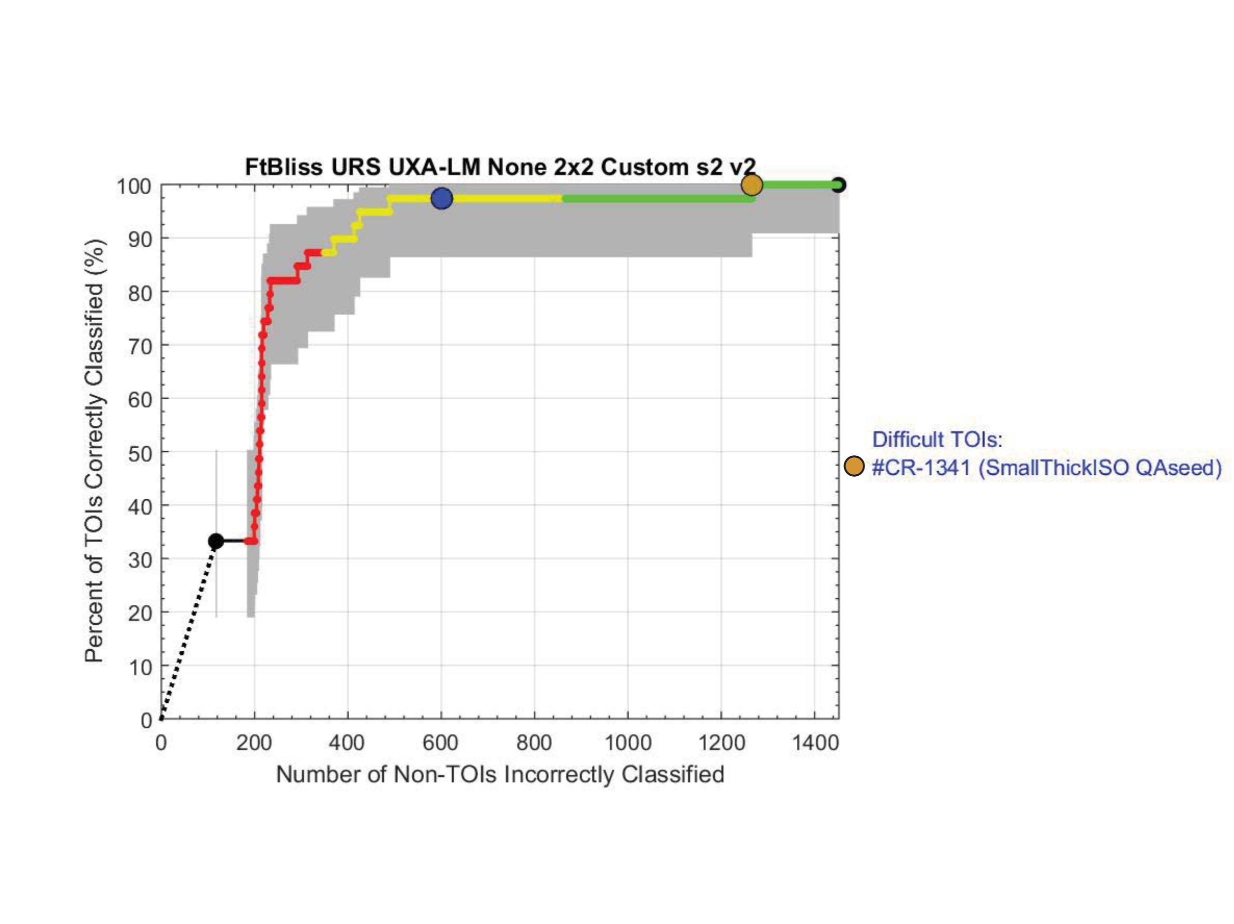

Figure 13. ROC Curve

6.4 FAILURE ANALYSIS

6.4.1 File Names and Target Flags

All cued anomalies were dug for confirmation (regardless of classification) during this demonstration project. However, both the flag names and flag locations were revised between field collection, initial processing, digging, and final classification. Refer to Section 9.2 for a summary of the file/flag name issues.

The target locations were refined and moved prior to digging based on preliminary analysis of the cued data (prior to completion of full classification) (i.e., the cued target flags and the dig target flags were different). Some dig locations were selected by the processor based on additional targets found during preliminary processing of the original target flag location's primary or re-collected cued data file (separated from the original cued flag after data collection via the alpha-numeric grid and anomaly numbers 500-n). Some dig flags were located farther than 40 cm from the center of the cued array (i.e., the inverted fit location was not under the sensor array). Additionally, the preliminary adjustment of the dig flag did not necessarily align with the final classified inverted fit location. The dig radius around each flag was 30 cm, so the anomalies (or lack of anomalies) identified in the cued data during full classification in some

instances was different than the items recovered by the dig team. A few of the deltas between the dig flag and TEMTADS array are due to renaming files to align with flag names that occurred after field work was complete.

For example, one cued file was associated with both CR-0858 (original target B5_88) and CR-0874 (additional target B5_500; no primary cued flag or cued file associated with this location). Upon renaming of dig target flags, the cued file was associated with dig flag CR-0874, and no cued data was transmitted for CR-0858 by ESTCP in the final demonstration files. However, the cued file should have been associated with the dig flag for CR-0858, which was only 21 cm away from the center of the array during cued data collection. CR-0874 was 90 cm away from the center of the array during cued data collection. It is unclear why preliminary processing resulted in the addition of CR-0874 at a distance so far from the original cued flag and array location. While there was only one cued shot associated with both dig flags, both locations were dug; a 0.50-caliber projectile was recovered at CR-0858, and frag was recovered at CR-0874.

6.4.2 Dig Target CR-1341

One seed was not identified in the final dig target list. The difficult TOI, target CR-1341 (seed 19) was a small ISO recovered at 23 cm bgs. A 21.5 cm tall rock was located on the surface, which affected the placement and height of the sensor array for the cued field measurement (Figure 14). The center of the cued shot array location met distance tolerances to the emplaced seed item location (34 cm); however, the highest library match was to a fuze part and the inverted item decision statistic was only 0.31, so the item was placed in Category 3 (Figure 15). Of note, one of the multiple object (111) solutions did match to a small ISO at 0.55, but the inverted location of the item was outside the sensor footprint and was therefore eliminated from further consideration. A visual review of UX-Analyze multi-source all solutions fit results did find possible solutions where the item was located within the sensor footprint, but the fit coherences were lower than the solution selected by UX-Analyze.

Figure 14. Seed 19 Emplacement

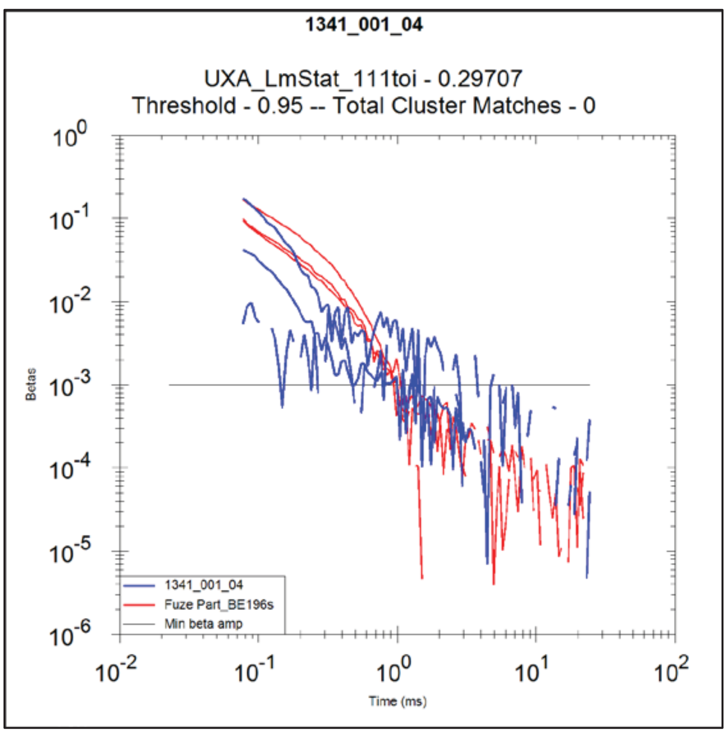

Figure 15. CR-1341 Cued Polarization

7.0 PERFORMANCE ASSESSMENT

The performance objectives for this demonstration are summarized in Table 1 and are repeated here as Table 4. The results for each criterion are discussed in the following sections.

Table 4. Quantitative Performance Objectives and Results

Performance Objective	Metric	Data Required	Success Criteria	Results
Data Collection Objectives				
Along-line measurement spacing	Point-to-point spacing from dataset	Mapped survey data	90% <25 cm along-line spacing	DQO achieved.
Complete coverage of the demonstration site	Footprint coverage	Mapped survey data	≥85% coverage at 0.6 m line spacing and ≥98% coverage at 0.75 m line spacing calculated using UX-Process Footprint Coverage QC Tool	DQO achieved.
Repeatability of IVS measurements	Amplitude of IVS seed items Measured target locations	Twice-daily IVS survey data	*Advanced Sensors Dynamic Survey:* RMS amplitudes ±30% at the 14th time gate. Down-track inverted location ±30 cm	DQO achieved except as noted in Section 7.3.
			Advanced Sensors Cued: Polarizabilities ±10%	DQO achieved.
Cued interrogation of anomalies	Instrument position	Cued mode data	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location	99.8% of anomalies. Refer to Section 7.4.
Detection of all TOI	Percentage of detected seed items	Location of seed items and anomaly list	100% of seed items detected with 60 cm halo	DQO not achieved. Refer to Section 7.5.
Analysis and Classification Objectives				
Maximize correct classification of TOI	Percentage of TOI placed in Category 1	Prioritized anomaly lists and dig results	Correctly classify 100% of TOI	97% of TOI. Refer to Section 7.6
Maximize correct classification of non-TOI	Percentage of correctly classified non-TOI	Prioritized anomaly lists and dig results	>75% of non-TOI classified in Category 3 while retaining all TOI	60%-70% of non-TOI. Refer to Section 7.7.
Specification of no-dig threshold	Percentage of TOI placed in Categories 1 or 2 and percentage of non-TOI placed in Category 3	Prioritized anomaly lists and dig results	Threshold specified to achieve criteria above	DQO not achieved. Refer to Section 7.8.
Minimize number of anomalies that cannot be analyzed	Percentage of anomalies classified as Category 0	Inverted cued mode data and prioritized anomaly dig list	Reliable target parameters can be estimated for >95% of anomalies on the sensor's detection list	DQO achieved.

Performance Objective	Metric	Data Required	Success Criteria	Results
Correct estimation of target parameters	Accuracy of estimated target parameters for seed items	Estimated and actual parameters (polarizabilities, XY locations, and depths [Z]) for seed items	Polarizabilities ±20% X, Y <15 cm (or 1 σ) Z <10 cm (or 1 σ)	DQO not achieved. Refer to Section 7.10.

7.1 OBJECTIVE: ALONG-LINE MEASUREMENT SPACING

Over 99.9% of the data met the along-line objective of less than 25cm spacing. This result was better than the performance objective of 90%. Figure 16 shows the sensor line path with separations larger than 25 cm flagged in blue.

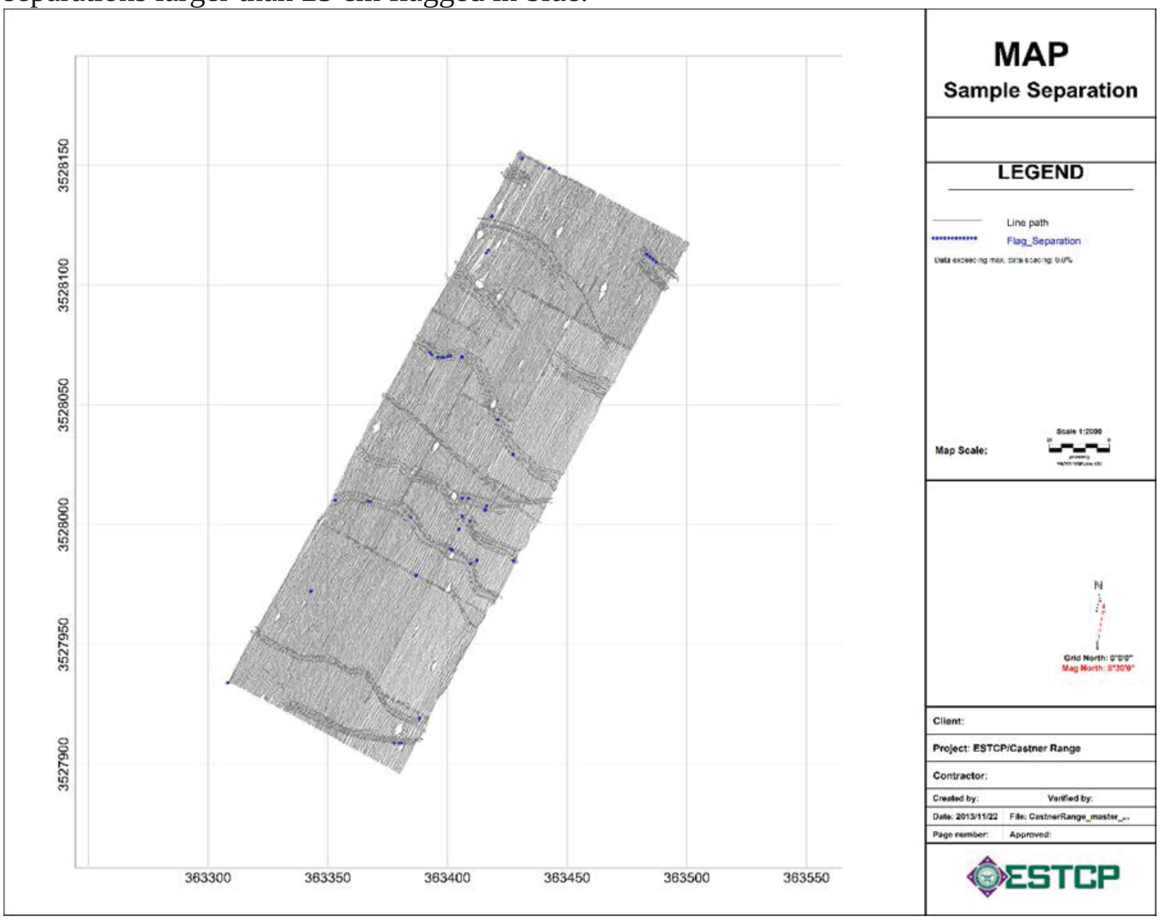

Figure 16. Sample Separation

7.2 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

The footprint coverage objectives of at least 85% coverage at a 0.6m instrument footprint and at least 98% coverage at 0.75m were met. When using a 0.6m instrument footprint, 95.6% of the survey area was covered. When using a 0.75m spacing, 98.9% of the survey area was covered.

This result includes areas that could not be surveyed due to vegetation. Figures 17 and 18 show coverage using a 0.6 m and 0.75 m instrument footprints, respectively.

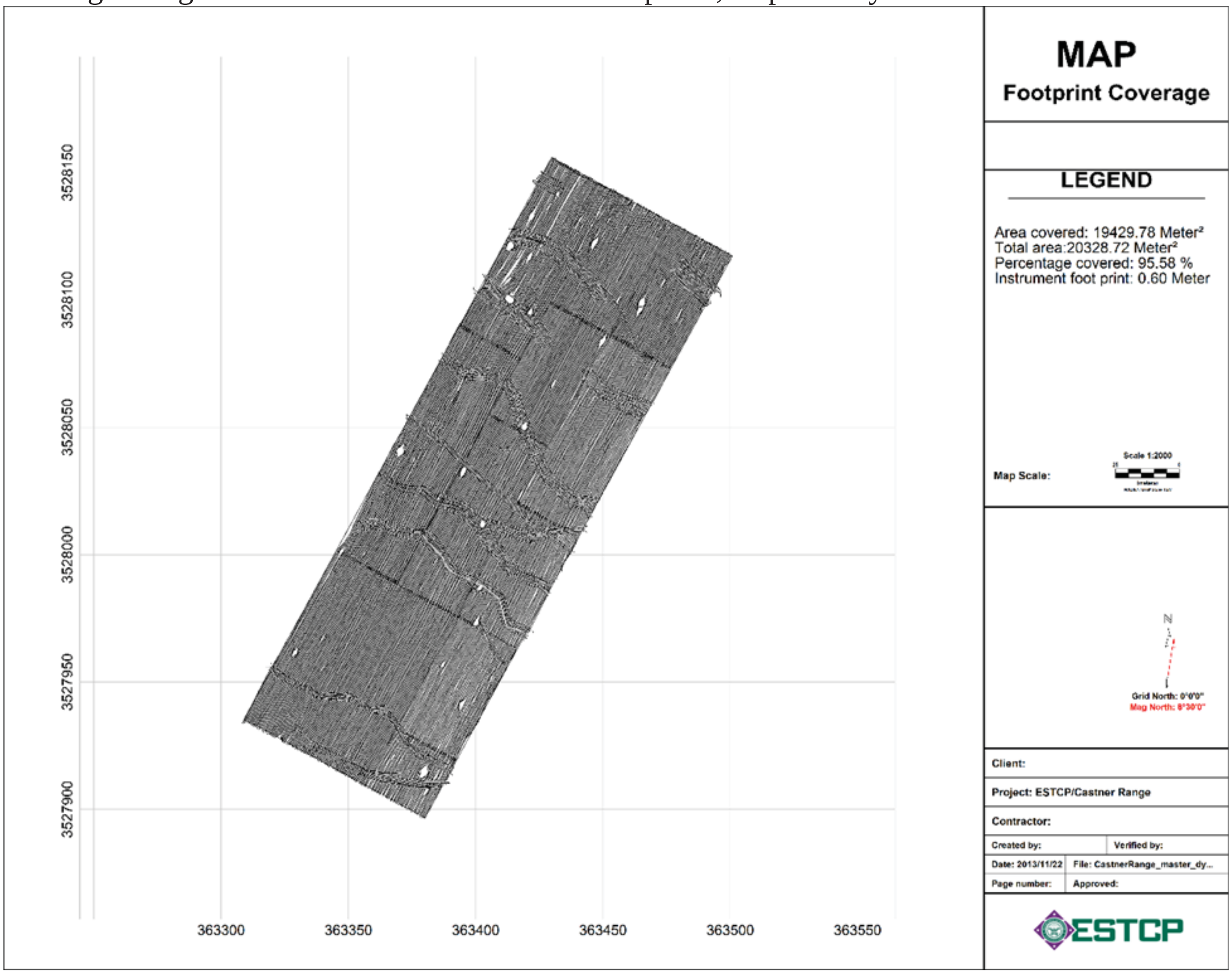

Figure 17. Footprint Coverage at 0.6 m

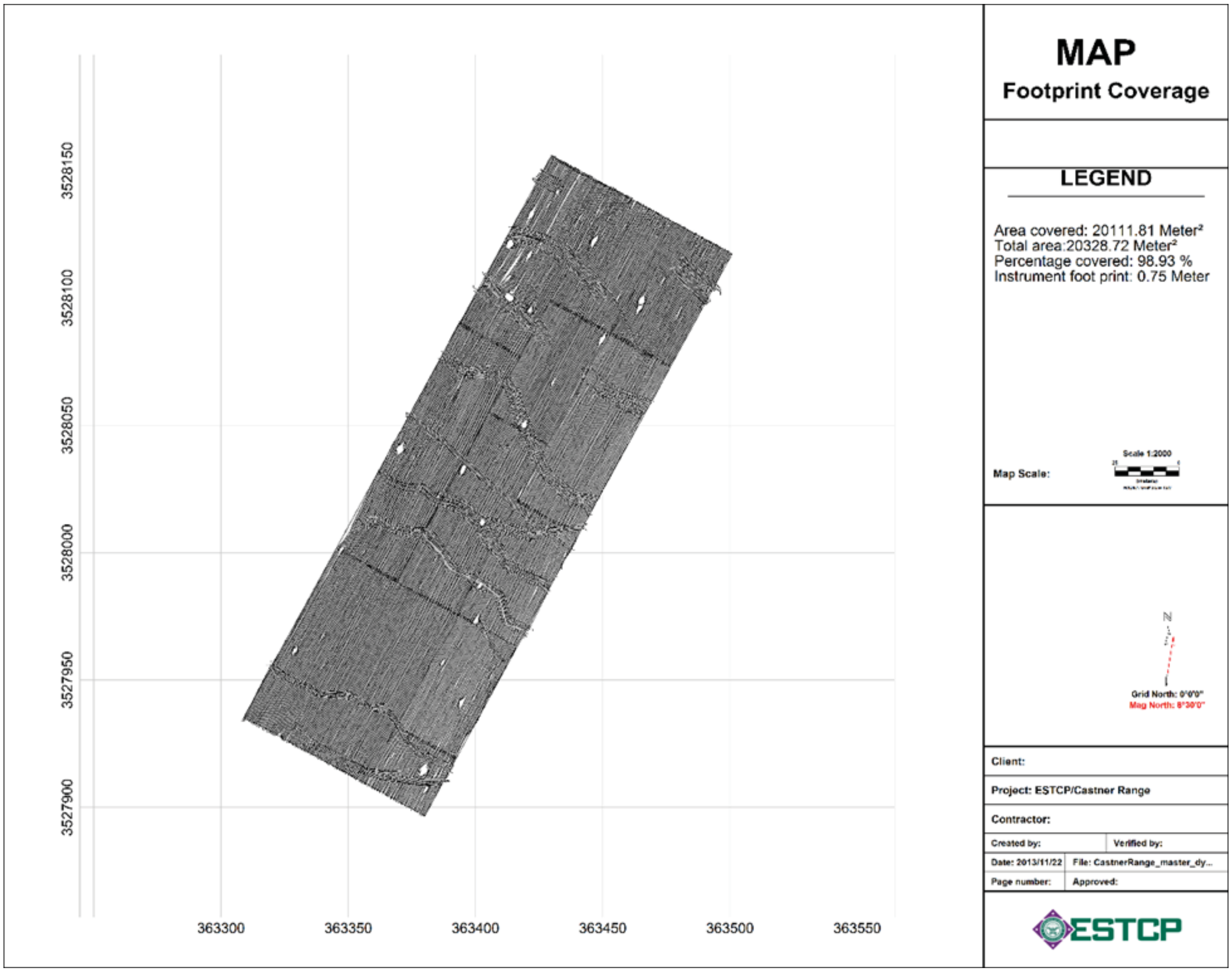

Figure 18. Footprint Coverage at 0.75 m

7.3 OBJECTIVE: IVS RESULTS

At the start of the project, the expected IVS dynamic response was calculated by collecting multiple IVS files and taking the average response. The sum of all four sensors at the 14th time gate was used for the comparisons. As the project progressed, the expected values were updated using a running average of all dynamic IVS data files.

A small percentage of the dynamic IVS tests did not meet the +/- 30% repeatability metric. In the IVS runs that failed, a response slightly outside of the criteria was measured over one of the five seed items. This may be due to inconsistent positioning with the litter. Slight deviations in line path and carry height can cause a higher or lower than expected response. The fiberglass handles were flexible, which resulted in variations in sensor height and caused a higher or lower than expected response. Having four smaller Rx sensors instead of one larger sensor (EM-61) may make the TEMTADS more sensitive to across-track deviations.

Since the exact polarizabilities of each seed item are not known (each seed was not measured for comparison), the polarizations were estimated by comparing against the highest library match for

each item. All cued seed items matched to a small ISO at 0.96 or higher. The deltas for the inverted locations in the X and Y directions were within 15 cm and the Z direction was within 10 cm.

7.4 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

For cued data collection, all but two of the instrument positions (99.9%) were within 40 cm of the cued flag location.

Of the 1,491 cued data files transmitted by ESTCP, 37 did not have unique target flags during cued data collection and therefore were not evaluated in this metric. These 37 dig locations were selected by the processor based on additional targets found during preliminary processing.

For the remaining 1,454 locations, the array was within 40 cm of the cued data collection flag for all except two locations. Target flag CR-1153 was located in an area of dense vegetation inaccessible to the array (86 cm from cued flag, 71 cm from dig flag). Target flag CR-1033 did not have an associated GPS file transmitted with the TEM file, so positioning information could be ascertained.

7.5 OBJECTIVE: DETECTION OF ALL TARGETS OF INTEREST

Sixty blind seeds (small ISO) were emplaced throughout the study area. Two of the seeds, seed 54 in grid C6 and seed 15 in grid C10, were neither identified during dynamic or cued data collection nor recovered during intrusive investigation. Seed 54 was close to a larger anomaly with a peak response close the target picking threshold. Seed 15 was slightly above the target picking threshold and its exclusion from the target list was an oversight. Of the 58 seeds that were recovered, 30 were in the dynamic-only study area and 28 were in the cued study area.

Within the dynamic-only study area, 22 of the 30 seed items (73%) were detected and located within a 60 cm halo of their predicted locations. Five of the eight missed seed items (17, 35, 50, 31, and 59) did not meet the target threshold response of 15 mV/A. Although we employed QC data checks during data collection (i.e., additional data collected in two survey directions over the seed locations), the use of a litter configuration in conjunction with the terrain and geology (variable instrument height), prevented us from selecting the seeds for cued analysis. While seed 48 did have a response higher than the target threshold, it was not identified as an individual anomaly because its peak response was smoothed out by gridding. Seed 38 was located near a larger anomaly, and therefore not selected as a separate anomaly. Seed 42 was not surveyed as it was inaccessible to the sensor (i.e., emplaced near cactus vegetation).

Within the cued study area, 26 of the 28 seed items (89%) were detected and located within a 60 cm halo of their predicted locations. Two seed items (seed 40/CR-0754 and seed 5/CR-0780) were not selected as cued targets based on interpretation of the dynamic data. Both seed items appeared in the dynamic data within large anomalies, but the location selected for cued data collection resulted in the seed item being outside the instrument footprint. The cued locations were placed on the prioritized dig list because of high library matches to a fuze, which were recovered on the surface at each dig flag location. This indicates that the peak response of the seed items were likely masked by the responses from the nearby fuzes.

7.6 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF TARGETS OF INTEREST

The prioritized target list identified 97% of the TOI in the dig portion of the list (Categories 1 and 2). This included a 105-mm projectile (MEC), 37-mm and 25-mm projectile frag (MD), and seeds. One TOI (CR-1341) was identified in the no-dig portion of the list (Category 3). Refer to Section 6.4.2 for additional information regarding CR-1341.

7.7 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TARGETS OF INTEREST

The prioritized target list identified only 60% of the non-TOI correctly. Fuzes were considered TOI in the final prioritized target list, which resulted in 148 additional non-TOI digs (Categories 1 and 2). If these high matches to fuzes were moved to Category 3, 70% of the non-TOI would have been identified correctly.

There were also three TOIs discovered that were not in the library, a 25-mm and two 37-mm projectiles. Finding these three TOIs required adding the cued data files to the library, which are not of ideal quality for library matching. The 25-mm projectile TOI resulted in 78 additional non-TOI digs for confirmation, with no other 25-mm projectiles found. The two 37-mm projectiles required an additional 137 digs, with 9 being TOI.

7.8 OBJECTIVE: SPECIFICATION OF NO-DIG THRESHOLD

The dig/no-dig threshold missed one difficult TOI by 665 digs, and only 60% of the non-TOI items were correctly labeled as non-TOI. Refer to Section 6.4.2 regarding the missed TOI (CR-1341) and Section 7.7 regarding non-TOI classification.

7.9 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Less than 5% of the anomalies were in Category 0, cannot analyze. This objective was met.

7.10 OBJECTIVE: CORRECT ESTIMATION OF TARGET PARAMETERS

Since the exact polarizabilities of each seed item are not known (each seed was not measured for comparison), the polarizations were estimated by comparing against the highest library match for each item. Figure 19 shows the primary polarizabilities (100: Size $\beta 1$) for the highest library match at the target locations where the 28 small ISO items were recovered in the cued area. For 25 of the 28 seed locations, the highest library matches for the primary polarizability were to small ISOs at greater than 0.92, the Category 1 threshold. These 25 locations are shown as the top grouping of $\beta 1$ in Figure 19. For three of the seed locations (indicated by the three lowest $\beta 1$ in Figure 19), the highest library matches were to items other than small ISOs. Cued locations CR-0754 (seed 40) and CR-0780 (seed 5) are discussed in Section 7.5, and CR-1341 (seed 19) is discussed in Section 6.4.2.

For the cued area, 43% of the dig flag locations were within 15 cm of the recovered item location and 93% were within 40 cm. Refer to Section 6.4.1 regarding flag location variabilities.

For the cued area, 93% of inverted estimated depths were within 10 cm of the recovered item depth. The overall mean error for all cued seeds was 1 cm too shallow, and the median error was even with the recovered depths.

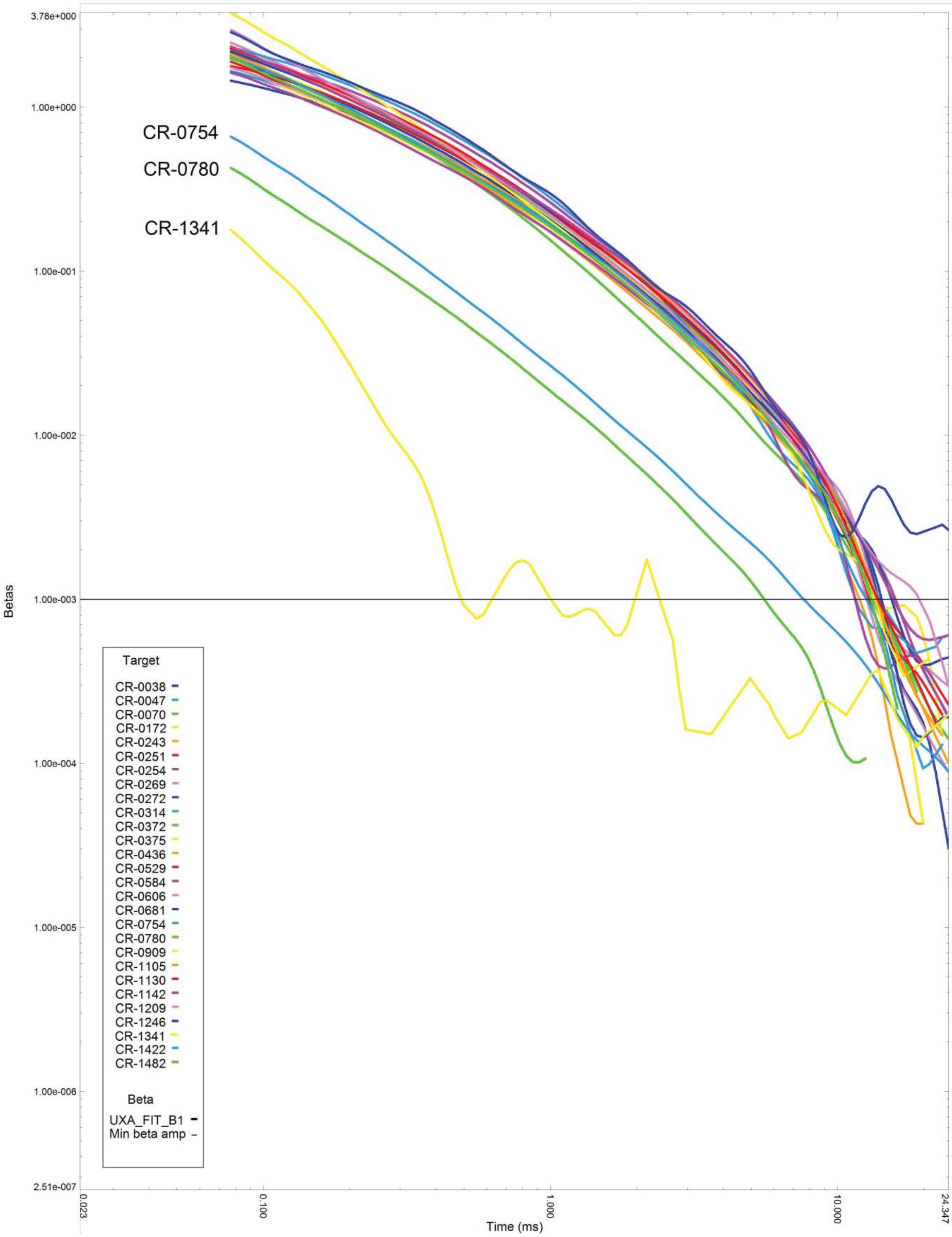

Figure 19. Primary Polarizabilities of Cued Seed Item Locations

8.0 COST ASSESSMENT

The cost elements traced for this demonstration are detailed in Table 5.

Table 5. Project Costs

Cost Element	Data Tracked During Demonstration	Estimated Costs
Project Planning	Develop project-specific documents: • Project Kickoff • Demonstration Plan • SSHP	$49,651
Site Preparation	Set up onsite project area Vegetation trimming Install blind seed items • Labor • Equipment rental • Supplies • Travel	$74,499
TEMTADS Data Collection	3-4 people (field team) data collection and processing • Dynamic data collection on 5 acres • Cued data collection on 2.5 acres: - 1,495 anomalies (2,200 cued shots including re-collect, background, and IVS measurements) Project Geophysicist • Equipment rental • Supplies • Travel	$120,140
TEMTADS Data Analysis/Classification	Dynamic: over 3,000 targets picked Cued: 1,491 targets fully classified	$24,202 29 minutes per anomaly $16 per anomaly$
Validation Digging	7 UXO Technicians Equipment rental Supplies Travel 1,525 targets (including recovery of 30 seed items in dynamic area) • 1,941 anomalies (including anomalies found in 30+ cm radius of target)	$259,990 $134 per anomaly $170 per target location

8.1 COST DRIVERS

The primary cost considerations associated with the selection and broad implementation of advanced geophysics and classification technologies are:

- Cost of data collection with advanced sensor arrays (primarily labor, per diem, and equipment rental/repair);
- Cost of data processing, analysis, and anomaly classification (primarily labor); and
- Cost savings associated with reduction in number of anomalies requiring intrusive investigation (primarily labor, per diem, and equipment rental).

A surface clearance was not conducted due to the Government shutdown. Uneven terrain (slopes, rocks) and vegetation precipitated the need to collect dynamic data using a hand-carried litter, which slowed production rates and added noise to the data. Several seeds were missed during initial processing using techniques within UX-Analyze available at the time of the demonstration project. The presence of ferrous rocks, frag, and small TOI resulted in additional digs.

8.2 COST BENEFIT

The primary driver for developing advanced geophysics and classification technologies is to reduce the total cost of executing munitions responses. DoD recognizes that a large portion of the munitions response budget is spent excavating and removing harmless metal fragments and non-munitions-related metal from MRSs. The implementation of advanced geophysics and classification has been demonstrated to reduce the total number of anomalies requiring intrusive investigation (i.e., excavation) by 60% to 90% in demonstration/validation projects. For advanced geophysics and classification to be broadly employed, these technologies must cost less to implement than the intrusive investigations that would be avoided by their implementation.

URS was able to correctly classify 60% of the non-TOI (70% if fuzes are not considered TOI) using TEMTADS 2x2 in litter mode and classification of cued data using UX-Analyze library matching. This could have resulted in cost savings associated 60-70% fewer digs than without using advanced classification. Using newer processing and classification techniques (e.g., dynamic inversion and classification) and better instrument attachments (e.g., litter poles with less flex) may result in better quality data that can achieve even fewer digs.

9.0 IMPLEMENTATION ISSUES

Advanced geophysical sensor and advanced data analysis methods in a production environment were used to characterize MEC hazards at CCR. Because URS' role in the Live Site Demonstration Program is to evaluate the implementation of these advanced sensors and classification methods from the perspective of a large-scale MMRP production company, URS documented issues/recommendations that will support implementation on an industry-wide scale.

9.1 TEMTADS 2X2 LITTER CONFIGURATION

9.1.1 Transport

The terrain and vegetation on Castner Range did not afford the field team the ability to locate the storage area near the study area so that the TEMTADS could be moved by hand. The equipment had to be placed in a pickup truck (Figure 20) and driven down a sloped and rocky dirt road to the IVS. URS used foam blocks and small equipment transportation cases, as suggested by NRL, to support and stabilize the system during transport but due to the rough unpaved road, the equipment underwent strong and sustained jostling while in transit. The bouncing was exacerbated by the fact that the pole configuration required the array to be placed sideways in the bed of the truck. This movement and the placement of the equipment placed stress on the equipment and risked damage to the coils and the cables attaching the computer and backpack to the array. The sideways placement of the array also required extra clearance from vegetation and hazards along the sides of the vehicle as the vehicle and cargo were essentially ten ft wide.

Figure 20. TEMTADS Loading for Transport to Study Area

9.1.2 Weight and Ergonomics

As mentioned in Section 2.2.1, the combined weight of the array (approximately 125 lbs) and backpack (approximately 35 lbs) required frequent breaks during data collection in an attempt to manage fatigue and avoid injury. URS-fabricated harnesses to help distribute the weight more evenly, allow some freedom of motion, and minimize slips, trips, or falls. The switch to an external frame pack configuration also provided a lighter and more ergonomic set up for sustained operation. However, despite these actions the field team was limited to an average of nine hours per day during dynamic data collection and ten hours per day for cued data collection. The physical strain was most significant on the person in the rear operator position carrying the backpack. Since the equipment was secured to the backpack and frequent personnel switches were necessary, the same backpack was worn by multiple users. Personal fit adjustments were limited, thereby making the ergonomics not ideal for every user.

9.1.3 Anomaly Locating

In prior studies, field personnel used a pole-mounted RTK GPS (i.e., detached from the geophysical equipment) to navigate to each anomaly location and emplace non-metallic pin flag marked with the anomaly ID prior to cued data collection. At CCR, rocky soil and weather conditions (i.e., wind) precluded the ability to place and retain flags. Painted marks were not a viable solution since vegetation and variable terrain did not allow the field team to mark the ground precisely.. Therefore, the field team used the RTK GPS mounted on the litter-configured TEMTADS along with the TSC controller to navigate to each point and immediately collect cued data. For the two-person cued data field team, this required the front operator to alternate use of both the TSC controller and the TETMADS tablet, as well as carry the litter. This led to frequent stoppages and repeated lifting and setting down of the equipment while finding each anomaly location. Rocks, vegetation, and/or terrain also added to the difficulty of centering the sensor over the anomaly location.

9.1.4 Length of Litter Poles and Bouncing/Swaying Array

The need to distance equipment and operators from the array to minimize interference required the use of long litter poles. NRL provided ten-ft fiberglass poles to suspend the array for the CCR project. In general, the litter configuration led to bouncing and swaying of the array during dynamic data collection that increased as walking speed increased. While some oscillation is unavoidable due to the natural walking motion, it was noted that the poles themselves also had flexibility. Additionally, the length of the poles precluded the ability to operate the array at a consistent height while traversing the narrow and steep arroyos. The bottom of the runners frequently touched the ground on either side at the top of the arroyo and the array was suspended at a much higher than the nominal survey height from the bottom center of the arroyo (Figure 21). This led to the appearance of false anomalies for the data collected at the tops of the arroyos and false clear areas at the bottom/inside the arroyos. As noted in Section 5.4.1, the field team walked additional transects parallel to arroyo features in an effort to obtain data with a more consistent array height. After completion of the CCR field work, NRL procured nine-ft litter poles made from sturdier carbon fiber, with handles to allow for adjustments in user heights.

Figure 21. TEMTADS Navigating Arroyo

9.1.5 Coil Failure

URS was able to achieve high rates of production for both cued and dynamic data collection averaging 120 cued anomalies per day (1,526 in 13 days) and 0.65 acres per day during dynamic collection (covering five acres in eight days). A transmitter board failure occurred the tenth day of data collection. Tablet readings showed abnormal readings on coil 1 and then registered a flat line (Figure 22).

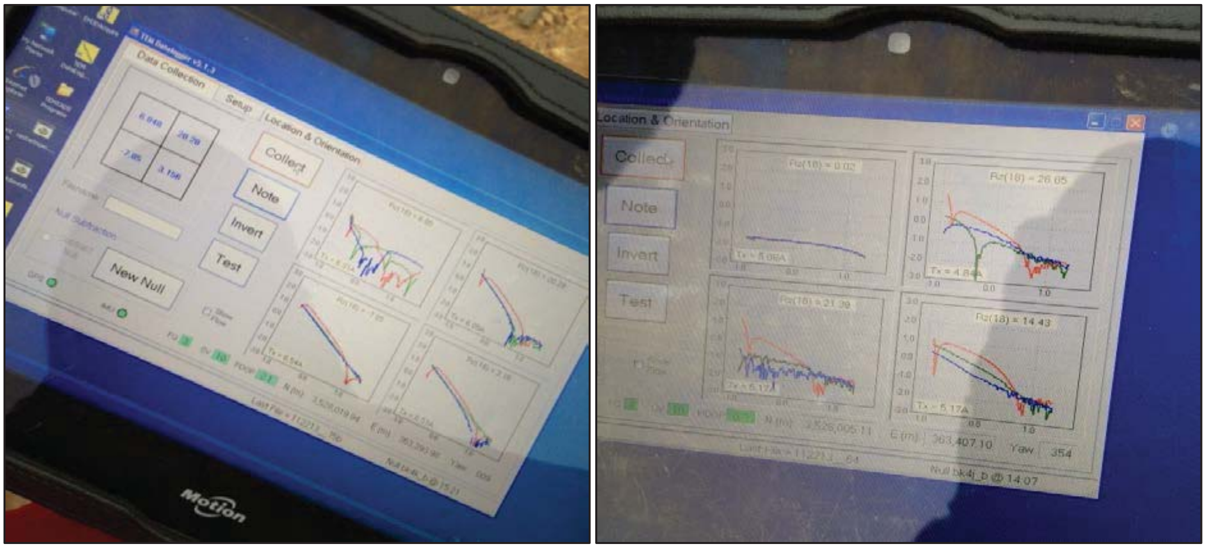

Figure 22. TEMTADS Tablet Displaying Coil 1 Failure

The field tablet allowed the team to recognize the problem quickly, but troubleshooting the problem took almost an entire work day. Initial attempts to check and replace the cables and batteries did not remedy the problem. The direct cause of the abnormal readings and coil failure could not be located. However, after switching coil 1 and 2, the TEMTADS began operating normally (Figure 23).

Figure 23. TEMTADS Coils Being Swapped

9.2 PROCESSING AND TARGET PICKING

9.2.1 Size and Number of Files

A typical data collection day for one team covered two thirds of an acre and yielded 800MB of raw data. After converting the raw .tem and .gps data files into .csv files and importing the data into a Geosoft database, a day of dynamic data was approximately 3GB. Because each data processing step took between 5 and 80 minutes, many steps were combined into automated scripts. The advanced sensor processing time made it difficult to experiment and discover better ways of handling the data (e.g., determining the best background subtraction files). The large data files make it very difficult to share and collaborate with non-local colleagues.

Cued data classification using the Geosoft Oasis Montaj Version 8.3 Processing menu was slow and caused multiple failures. After troubleshooting with the software developers, the errors were attributed to lack of computer space (files were inexplicably reaching 10s of GB without defragmenting) and available memory (after multi-day continuous processing runs). URS acquired a new computer and worked with the developers to run the Processing menu in shorter pieces with manual checks and file management between each process.

9.2.2 Standardized Workflow and Parameters

While a user's manual exists for the TEMTADS 2x2 instrument, limited guidance for processing data in UX-Analyze was available during the CCR demonstration project. A robust user's manual that includes guidance and standard parameters would be beneficial for future implementation.

The standard TEMTADS library did not contain every TOI found at CCR. Cued data files associated with three items found at CCR were added to the library for matching, but the cued data were not of ideal quality and resulted in additional matches to non-TOI.

9.2.3 File Naming

Anomaly flag names were revised between field collection, initial processing, digging, and final classification. Initial flag locations were provided to the field team for cued data collection. Upon collection, the field team named the files by date and a sequential file number. The processor renamed by the files to align with the grid (alpha-numeric) and anomaly number (each grid numbered 1-n) designation. These alphanumeric target numbers were used by the processor for initial classifications and the dig team for intrusive investigation. However, the targets names were incompatible with the classification workflow in UX-Analyze, so the targets were renamed again to have a unique numerical identifier throughout the cued study area (CR-0001 to CR-1495). Crosswalk files link the renamed targets to the cued data collection files; however, the renaming process via Geosoft UX-Target resulted in some errors.

While the final renamed files (e.g., CR-0001) were imported into UX-Analyze, additional errors occurred. URS worked with the software company and determined it was related to the use of a hyphen instead of an underscore in the file name. Resolution was to rename all of the cued files, reimport into UX-Analyze, and re-process the data.

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Appendix A: POINTS OF CONTACT

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